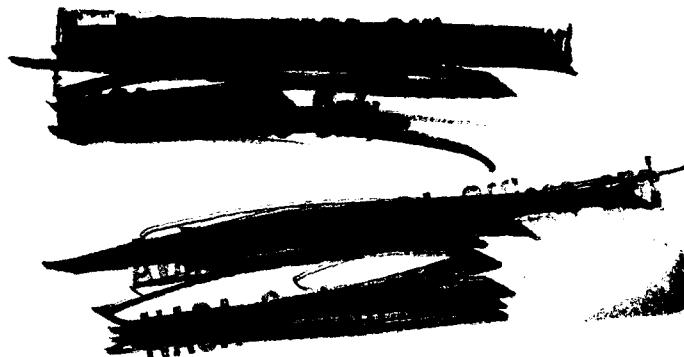THIRD SEMIANNUAL PROGRESS REPORT

December 1964

NASA Grant NsG-496

UNPUBLISHED PRELIMINARY DATA

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Center for Space Research

THIRD SEMIANNUAL PROGRESS REPORT

For the Period

June 1, 1964 to November 30, 1964

on

NASA GRANT NsG-496

To The

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Office of Grants and Research Contracts

FOREWORD

This third semiannual progress report on the projects comprising
the general research program of the Center for Space Research
reflects a considerable growth in the program since its inception.
As is pointed out in the first two reports, the intent of the
general program is to stimulate so-called seed research in broad
space-related fields in engineering, the physical sciences, the
life sciences as well as in the social sciences.

The program is made possible by a grant, NsG-496, from the National
Aeronautics and Space Administration. However, the selection and
approval of projects within the program is a responsibility of the
Center for Space Research and is discharged with the assistance of
a technical committee and of a policy committee, whose members are
listed in the Appendix. We note after some year and a half of
experience with this kind of institutional grant that it continues
to be appropriate support for a university laboratory and is par-
ticularly important for our Space Center. The variety of research
that can be truly stated to be space-related is exceedingly large,
and the flexibility to shift support between fields as ideas emerge
is of very great value.

The individual reports might not reflect the growing interrelated-
ness between research in the life and physical sciences and inves-
tigations in the engineering area which the multidisciplinary
interests of the Center have helped bring about. For example, the
research done within the Department of Nutrition and Food Science
on the effect of diet on man's performance in certain control tasks
is strengthened considerably by using tasks occurring in manned
space vehicles control studies underway within the Department of
Aeronautics and Astronautics. Similarly, the possibilities for
pertinent social science and industrial management research, using
as case histories certain of the Center's experiments in space,
have not gone unrecognized.

While the general research program of the Center reflects only a
portion of MIT's overall activities in space research, it never-
theless is a crucial portion which provides much of the adminis-
trative flexibility needed to stimulate the growth of new ideas.

J. V. Harrington, Director
Center for Space Research

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PHYSICAL SCIENCES AND ENGINEERING

SOLID STATE ENERGY CONVERSION PROCESSES

Investigators: J. Blair, G. S. Almasi, A. S. Carlson, J. W.
                 Conley, P. J. Shaver

Project No.:   DSR 9827

Introduction

The purpose of this research is to study fundamental problems
associated with photovoltaic and thermoelectric energy conversion
processes primarily in connection with the utilization of solar
energy in space applications.

Optical Absorption Edge in Cadmium Telluride

The mechanism responsible for the optical absorption in this compound
semiconductor at the threshold of the fundamental edge at low temp-
eratures has been identified. The process involves creation of an
exciton and destruction of a phonon from the longitudinal optical
band of the lattice vibration spectrum. The results of theoretical
analysis and experimental observation are in quantitative agreement.
The results obtained are consistent with a band structure model
having a direct forbidden energy gap.

In performing the physical experiments an optical cryostat was de-
signed in which the sample was immersed in helium exchange gas. The
temperature of the sample was fixed at values in the range from 4.2
to 140° K and high resolution optical transmission spectra were
obtained.

The temperature dependence so obtained is explained in terms of both
the shift of the fundamental edge with temperature and also the
change in occupation (Bose) probability of the LO phonon modes.
Further, the effects of sample surface preparation were studied.
With respect to these observations, additional theoretical calcula-
tions on the effect of imperfect surfaces and bulk defects has been
initiated.

Thermal and Electronic Transport Properties of Zinc Antimonide

Zinc antimonide is an anisotropic semiconductor with good thermo-
electric characteristics in the moderate temperature range. Large
single crystals of ZnSb are being produced on a routine basis. All
electrical and thermal measurement programs are progressing satis-
factorily. Thus far, measurements on this orthorhombic semiconductor

indicate no anisotropy, in the thermoelectric power, about a 15
percent variation in thermal conductivity, and a 100 percent varia-
tion in electrical conductivity between the three principal axes.
Copper doping is used to control the hole concentration in these
crystals. Magnetoresistance and Hall effect measurements are still
incomplete but, at present, they seem to indicate a simple valence
band structure in zinc antimonide.

A Graded Energy Gap Photovoltaic Device

Previous project reports have described preliminary experimental
results on a graded-energy-gap photodevice. These results were
obtained with equipment made available by the National Magnet
Laboratory.

Since that time, work has centered on setting up the equipment
necessary to make a more thorough experimental investigation of
photoeffects in graded-gap semiconductor regions here at the Energy
Conversion and Semiconductor Laboratory. A liquid-helium research
dewar, an infrared monochromator, and most of the necessary asso-
ciated equipment have been obtained and are now being assembled into
a working measuring setup.

In addition, the analysis of the graded-energy-gap device has been
extended to include operation under high illumination and operation
without a magnetic field.

A Multi-Transition pn Junction Photovoltaic Cell

High efficiency solar cells can be achieved with a proper material
which provides a good match to the solar spectrum. Direct transi-
tion processes make use only of photons with energy equal to, or
higher than, the energy gap. Indirect transition processes, made
possible by the presence of impurity levels in the forbidden gap
can absorb low energy photons and bring them to the conduction band.
A higher efficiency is then expected.

The requirements imposed upon the material are strict. Little is
known about the physical properties of traps deliberately added to
the material. CdS seems to suit the purpose best and shows much
promise. Other workers have reported an efficiency as high as 7
or 8 percent with solar cells made out of CdS. Investigation of
the properties of CdS in order to determine the relevant parameters
and of possible ways to modify them to obtain optimum values accord-
ing to theoretical calculations is being carried out.

CONSTITUENTS OF TEKTITE AND METEORITES

Investigators: W. H. Pinson, P. M. Hurley, J. W. Winchester,
                 G. D. Roe, R. M. Shields, J.-G. Schilling

Project No.:   DSR 9835

Rubidium-Strontium Analyses of Ultramafic Rocks and The Origin of Peridotites

In completing his work on this part of the project, Mr. Roe shows that mass spectrometric measurements on peridotites demonstrate that many of them have Sr^{87}/Sr^{86} and Rb/Sr ratios higher than oceanic basalts, and most of them contain less than 0.4 ppm Rb and 10 ppm Sr.

The surprisingly high Sr^{87}/Sr^{86} ratios of many peridotites cannot be correlated with both the Rb/Sr ratio and the time of intrusion. Although the Rb/Sr ratios are higher than expected for subcrustal material, the Sr^{87}/Sr^{86} ratios cannot have reached such high values from Rb^{87} decay unless the peridotite existed as a separate system for a much longer time than indicated by the intrusive relations.

A 730 m.y. isochron for dunites from the New Zealand-New Caledonia area is interpreted as dating a partial melting event in the upper mantle which left the dunite as a residual material after removal of the basaltic liquid. Subsequent mobilization and intrusion of the dunite did not change its Rb-Sr systems. Measurements on such peridotites, which have high Sr^{87}/Sr^{86} ratios, are used in conjunction with the oceanic basalt measurements of Faure and Hurley (1963) to develop an upper mantle history, in which the major events are:

    1. Early differentiation

    2. Later partial melting and separation of basaltic and
        peridotitic phases

    3. Subsequent intrusion

It is postulated that the basalts contain nearly all of the initially available Rb and Sr. They are essentially whole-rock samples of the upper mantle. Their Sr^{87}/Sr^{86} ratios can be extended back in time according to their Rb/Sr ratios past the partial melting event, which separated them from the original mantle material, to the time of the original mantle differentiation. On the other hand, the peridotites, containing very little of the Rb and Sr, have Sr^{87}/Sr^{86} ratios which extend back in time only as far as the partial melting event.
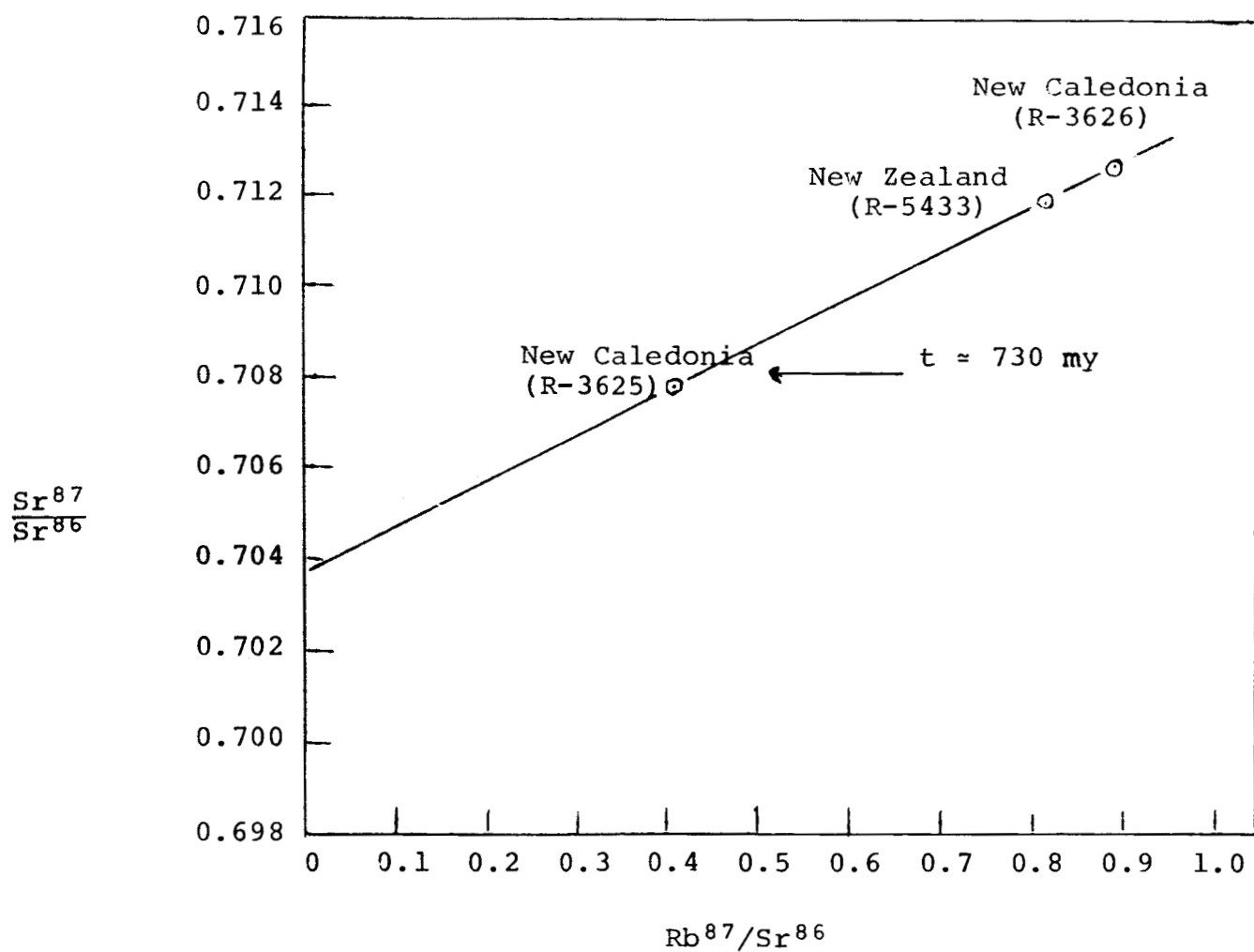
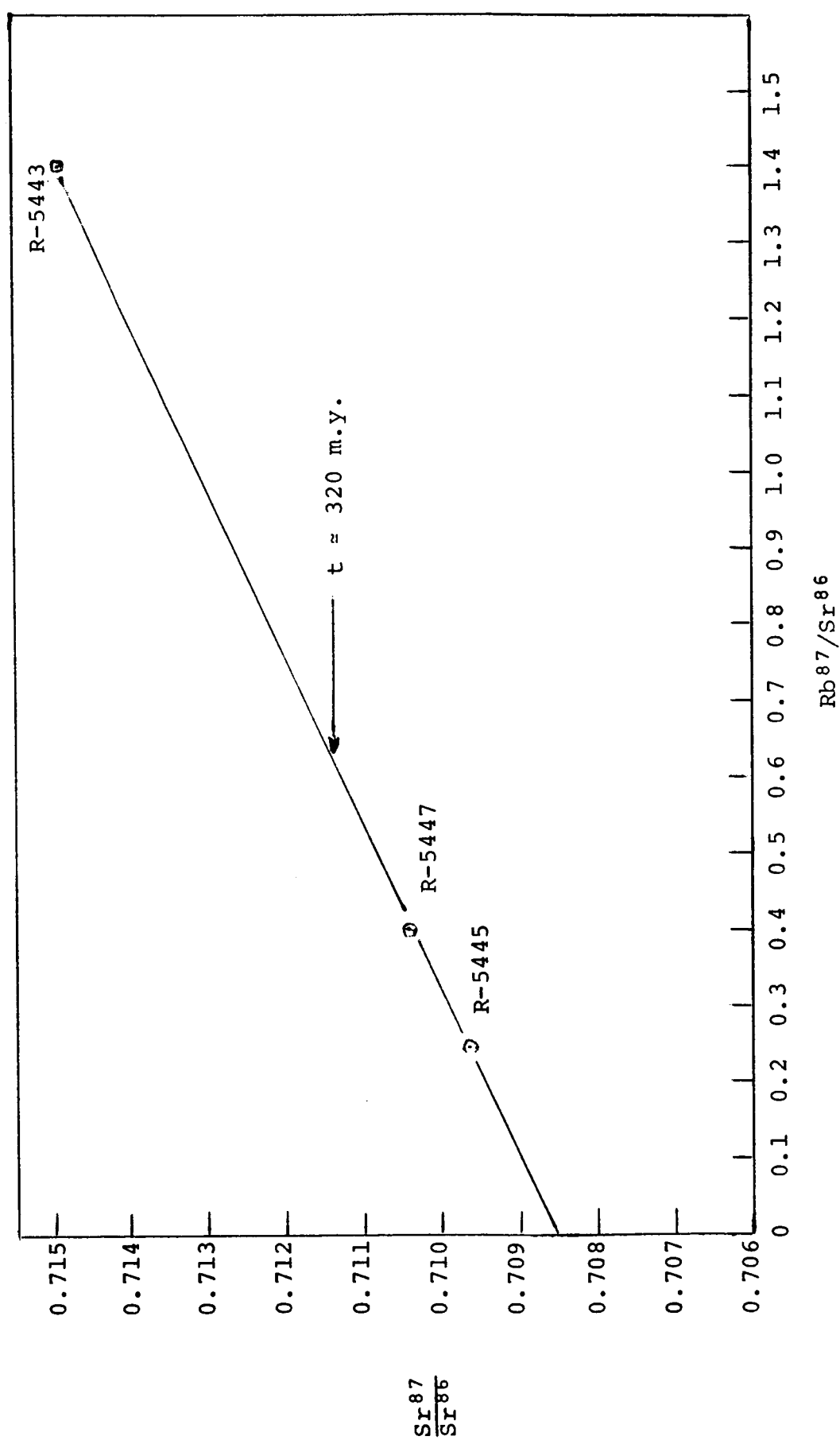Figure 1. An isochron plot for dunites from New Caledonia and New Zealand

Figure 2. An isochron plot for two peridoties from Black Lake, Quebec, and a serpentinite from Lowell, Vermont

The Rb^{87}-Sr^{87} Age of Stony Meteorites

Mr. Shields has completed refined Rb^{87}-Sr^{87} age measurements on three
stony meteorites: Pasamonte, a eucrite; Bath, an olivine-bronzite
chondrite; and Bruderheim, an olivine-hypersthene chondrite. Each
of these meteorites is a "fall" and was selected for its freshness
of appearance and contamination-free history. The analyses of
these three meteorites have been combined with the analyses of
three other fresh meteorites--Murray, a Type II carbonaceous chon-
drite analyzed by Beiser (1964), and Nakhla, a nakhlite, and
Estherville, a mesosiderite, analyzed by Pinson et al)1963)--for
the construction of a highly precise meteorite isochron. These
six specimens possess a wide spread of Rb^{87}/Sr^{86} and Sr^{87}/Sr^{86} ratios
and yield a $4.45 \pm 0.03 \times 10^9$ years isochron ($Rb^{87} = 1.39 \times 10^{-11}$
years^{-1}) with an initial Sr^{87}/Sr^{86} ratio of 0.6982. If one assumes
that the Pb-Pb and Rb-Sr techniques give the same age for meteorites,
a decay constant of 1.36×10^{-11} year^{-1} can be calculated for Rb^{87}
by comparing the Rb-Sr data with the Pb-Pb age of 4.5×10^9 years
(Patterson, 1956). Insofar as the sampling has been carried out
and within the precision of the measurements, all stony meteorites
are of identical age. The major contribution of this work lies
in the achievement of a high degree of analytical precision.
Improvements in both the chemical and mass spectrometric techni-
ques of analysis have made possible the precise measurement of
exceedingly small quantities of Rb and Sr such as are found in
meteorites and some ultramafic rocks.

Several phases were also separated from the Bjurbole chondrite for
Rb-Sr analyses. The results, however, indicate that this chondrite
is severely contaminated.

Fully Automatic Step-Elution Chromatography for Rare Earth Separation

Mr. Schilling has continued his work on the separation and analysis
of a group of similar elements such as the rare earths, which is
proving a difficult and time-consuming problem. A rapid procedure
utilizing chromatographic separation of neutron-induced, low-level
radioactivies was developed (J. W. Winchester, 1963; D. G. Towell,
1963). In this procedure, two analysts working jointly could
analyze up to three samples per week, which was faster than methods
commonly used. Nevertheless, before undertaking a wide survey of
the rare earth concentration and fractionation in basaltic rocks
and their ultramafic inclusions, it was found desirable to increase
the possible number of samples to be analyzed per week.

A fully automatic step-elution chromatography for the rare earth
separation was developed. The acids of different concentrations
are poured sequentially by means of a binary electronic counter
(see Figure 4). This counter is followed by a binary-to-decimal
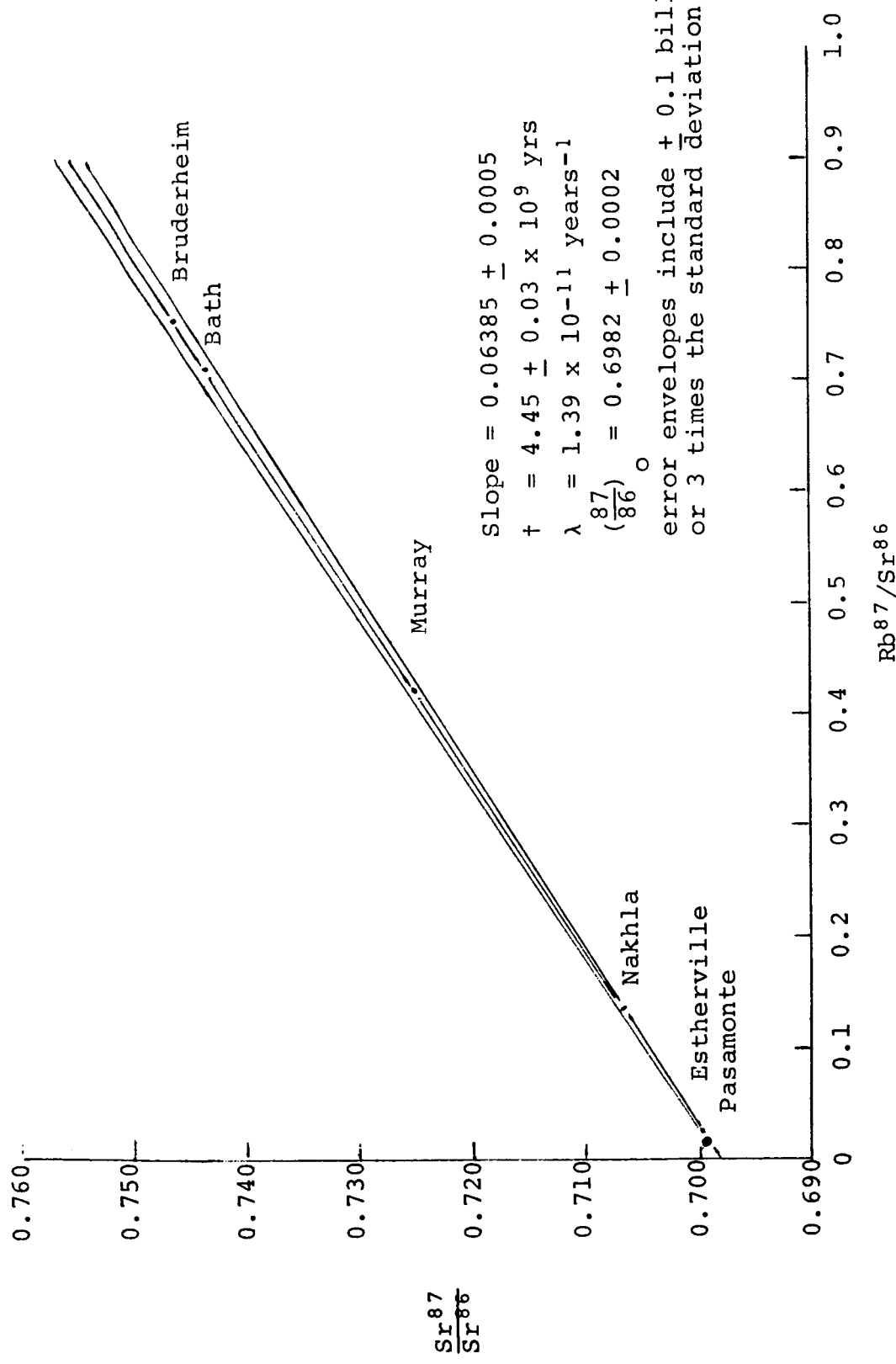
Figure 3. Shields' Meteorite Isochron

decoder used to activate the solenoid values controlling the flow of the acids. The scanning and on-off information for the selection of the valves are provided by two level electrodes placed above the chromatographic column. To avoid any electrolysis, the two electrodes are supplied with a 1000-cps oscillator. The electronic system provides also a manual control for each solenoid valve, as well as a preselector for the end-point of the elution. The circuit is entirely solid-state designed and is flexible enough so it could be extended to other similar chromatographic techniques. With such a system, four to eight analyses per week can be performed with only two analysts. The elution time can be extended from three to six hours, thus improving significantly the kinetics of the ion exchange reactions, which will in turn give a better separation of the rare earths.

The latter improvement could be used eventually to eliminate any gamma counting, leaving beta counting which is rapidly done with a low background proportional counter and automatic sample changer. Such a counting procedure still remains to be tested.

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1. Roe, G. D.: "Rb-Sr Analyses of Ultramafic Rocks and The Origin of Peridotites," Ph. D. Thesis, M.I.T., 1964.

2. Shields, R. M.: "The Rb-Sr Age of Stony Meteorites," Ph.D. Thesis, M.I.T., 1964.

3. Pinson, W. H., C. C. Schnetzler, H. W. Fairbairn, E. Beiser, and P. M. Hurley: "Rb-Sr Age of Stony Meteorites," Geochim. et Cosmochim. Acta (in press).

4. Winchester, J. W.: J. Chromatog. 10, 502, 1963.

5. D. G. Towell: Ph. D. Thesis, M.I.T., 1963.

Figure 4

PROBLEMS IN ASTROPHYSICS

Investigators: C. C. Lin, L. N. Howard, D. Lortz, A. Toomre,
L. Mestel, W. Julian, R. Rehm, F. H. Shu
Project No.: DSR 9836

1. Solar Convection Zone and Solar Corona

Magnetoconvection

A general stability criterion for steady finite amplitude convection, mentioned in the previous report, has been applied to the case of a convection layer which is rotating about a vertical axis and in which an external vertical magnetic field is present. Furthermore, certain diffusion processes are taken into account, which lead to addition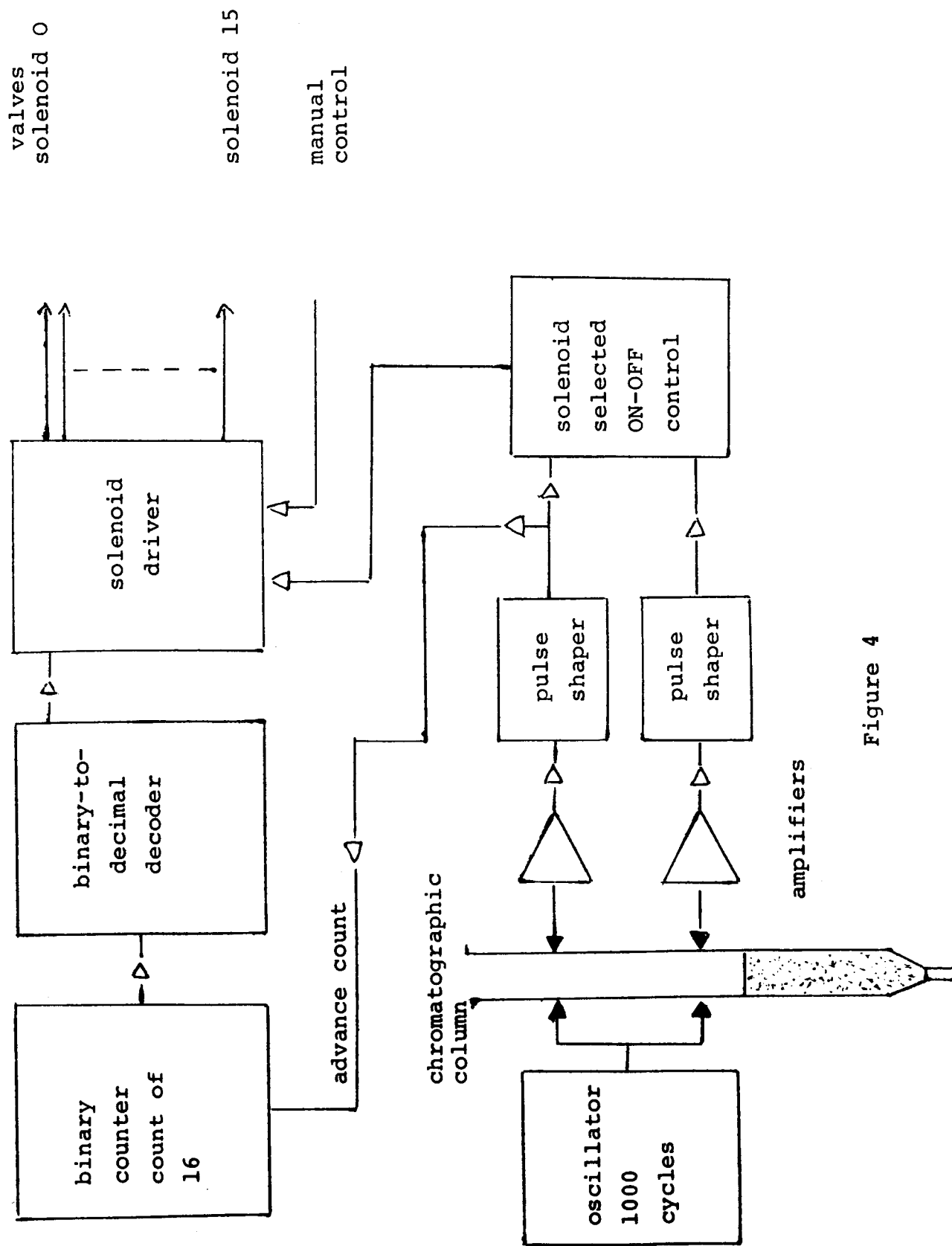al buoyancy forces besides the effect of thermal expansion. The deduced stability criterion, demonstrated for two rigid bounding surfaces which are perfect thermal and electrical conductors, is applicable to more general kinds of boundary conditions.

Another present work is concerned with some kind of a dynamo problem. A physical model for the origin of the stellar magnetic fields has been developed. In the limit in which the magnetic diffusivity η is very small compared with the thermal conductivity κ it is possible to apply a method which allows to approximate nonlinear steady solutions for the motions and the magnetic field. The limit $\eta/\kappa \ll 1$ seems to hold in most astrophysical applications. For instance, in the convection zone of the sun η/κ is about 10^{-7}. The second order of the iterative procedure yields the usual dynamo equations of magnetohydrodynamics with a velocity field derived from the linear equations of convection. The treatment of these equations is the essential part of the theory and is not yet finished. Some results have been obtained for small velocity amplitude and for very large amplitude. However, the desired generation of the magnetic field, which is an instability, has not yet been found. Nevertheless, there is some hope of proving that the instability exists, which is indicated by certain Fourier truncations. The problem is essentially three-dimensional because one can show that, for example, two-dimensional flows are not able to generate a magnetic field. This seems to be the reason why the closely related theory of the origin of the geomagnetic field is relatively incomplete.

2. Gravitational Instability

A. Spiral Arms and Spiral Patterns

It is demonstrated (Toomre and Julian) that a prominent spiral arm will be formed by the presence of a single mass point travelling

with mean circular velocity. Calculation of a spiral pattern is
progressing (Rehm) and various new ideas are being developed for
the explanation of the mechanism for the formation of spiral pat-
terns (Lin and Mestel). This includes the consideration of pres-
sure effects in the gas, random dispersion of stellar velocities
with the resultant Landau damping. The roles played by the
various effects are becoming better understood, and several
concrete suggestions are now being examined to demonstrate these
ideas.

B.   The Gravitational Collapse of a Uniform Spheroid

A uniform, nonrotating, pressure-free spheroid is supposed to
collapse gravitationally from rest. It is shown that the initial
eccentricity is steadily increased by the anisotropic gravitational
field: an initially oblate spheroid tends towards a disk, and an
initially prolate spheroid towards a spindle. Numerical results
are computed for a series of initial eccentricities.

INTERPLANETARY GAS FLOW ABOUT PLANETS

Investigators: M. Finston, E. E. Covert, M. P. Friedman,
                C. J. Bartlett
Project No.   DSR 9837

The propagation of small amplitude waves in the solar wind has been investigated with the use of a microscopic model for the plasma. The problem is a very complex one in that the behavior of a wave depends upon the type (longitudinal or transverse), frequency and wave number of the wave, its direction of propagation relative to a magnetic field and the shape of the plasma distribution function. The temperature and density of the solar wind plasma have been reasonably well established from satellite data. Furthermore, there is evidence for the presence of a magnetic field of 10^{-4} gauss. This evidence indicates that the magnetic field may be turbulent. However, there is little or no information about the shape of the plasma distribution function. Because the large number of possible propagation modes and types of unstability depend so critically upon the little known plasma properties, attention has been concentrated upon the simplest mode of oscillation, the electrostatic mode.

Electrostatic (plasma) oscillations are basic to the nature of a plasma. Their existence depends upon the Coulomb interactions between particles. It is well known that two contra-streaming plasmas may be unstable to these waves[1] (two-stream instability), and these instabilities may provide a mechanism for the transfer of momentum between the streams. Hoyle and Harwit[2] have shown that such a coupling mechanism is not sufficiently strong to account for the observed deflection of comet tails in the solar wind flow. However, their analysis is based upon the linearized Vlasov equation which can predict the initial growth of a disturbance but not the final equilibrium state which the plasma will attain. Furthermore, Stix (Ref. 1, p. 154) has pointed out that electrostatic instabilities have been found experimentally under conditions which the linearized Vlasov equation predicted to be stable. These considerations suggest a somewhat different approach to the problem of plasma waves than the one conventionally used.

A full momentum-space description of the plasma is being attempted. The approach is classical in that a particle is assumed to have a point charge and mass. The Liouville equation for the ensemble distribution $F^{N,N}$ of N particles may be integrated over $N-\nu$ spatial variables to obtain a hierarchy of equations for the function $F^{N,\nu}$ of N velocity and ν position coordinates. A typical member of this hierarchy has the form

$$\frac{DF^{N,\nu}}{D t} = \mathcal{L}(F^{N,\nu+1},\ F^{N,\nu+2}) \qquad [1]$$

This hierarchy of equations is entirely equivalent to the Liouville equation, and a simplification is achieved only if a closure to the hierarchy is found. Such a closure has been found leaving three coupled equations for $F^{N,o}$, the spatially-homogeneous N-body momentum distribution, $F^{N,o} + h^{N,1}$, the generalized single particle distribution, and $g^{N,2}$, the generalized two-particle correlation.

If spatial correlation effects are neglected ($g^{N,2} \sim o$) and a spatial Fourier transform is taken, the equation for the spatial inhomogeneities has the form

$$\frac{\partial h^{N,1}}{\partial t} + i \ H^{N,1} = 0 \qquad\qquad [2]$$

This equation can be reduced to the linearized Vlasov equation by integrating over N^{-1} velocity variables and introducing a further simplifying assumption. The operator H contains only real elements and is self-adjoint, and the normal modes are stable in the sense that their amplitude will neither increase nor decrease with time. It seems possible that from a knowledge of these normal modes, when the level of description of the plasma is reduced to that of the distribution function for a single particle, some further insight into plasma instabilities and the way in which their amplitude is limited may be gained.

References

1. Stix, T. H.: The Theory of Plasma Waves, McGraw-Hill (1962).

2. Hoyle, F. and N. Harwit: Astrophysical J. 135, 867, 1962.

3. McCune, J. E.: Physics of Fluids 7, 8, 1306, Aug. 1964.

ELECTRODE STUDIES IN MAGNETOGASDYNAMIC

GENERATORS AND ACCELERATORS

Investigators: M. A. Hoffman, G. C. Oates
Project No.:   DSR 9838

An understanding of the current behavior in segmented electrode geometries when operating in a diffuse current mode is fundamental to the interpretation of the operating behavior of linear MGD generators and accelerators. Investigations of the electric current distribution in magnetogasdynamic devices which employ steady linear flows are now in progress.

Initial experiments were performed on a heat-exchanger facility using a 30 kw plasmagun as the basic heat source. A small test section of boron nitride with three pairs of tantalum electrodes was used in the first runs. The test-section flow channel was 0.5 x 0.7 cm in cross section and 6.25 cm long. The plasma consisted of 1 g/sec of argon seeded with a small amount of potassium.

It was found that the test section could not be made to operate in the diffuse current mode because not only was the plasma enthalpy too low to raise the electrode temperatures sufficiently, but the potassium seed-flow system was also limited in capacity, so that insufficient coating of the electrodes was obtained. As a result, a diffuse current could not be supported at current loadings of more than a few milliamperes and an arcing mode was encountered.

A modified facility has been constructed around the plasmagun used in the previous experiments. The plasmagun now feeds directly into a graphite plenum, in which the high-temperature gas from the arc is mixed with a secondary flow which is preheated in a pot of molten lead. Immersed in the lead pot is a stainless steel potassium boiler which feeds precise amounts of potassium into the secondary flow. The combined flows then are fed into a test section mounted on top of the plenum.

Initial runs on this facility have yielded some interesting results. A somewhat larger boron-nitride section with a 1.5 x 1.5 cm cross section was used (Figure 1). The electrode configuration once again consisted of three pairs of tantalum electrodes with the center electrode subdivided into three sections. Measurement of the current to each section of the electrode gives a three-point current distribution. In addition, extensive probe measurements were provided for.

Typical experimental results are shown in Figure 2. The working fluid employed was a mixture of argon and nitrogen seeded with potassium at a gas temperature of about 1500° K.

Preliminary theoretical results are also indicated. The theoretical model assumes uniform velocity, temperature and electrical conductivity of the gas flow. In addition, the theory assumes a constant electrode potential and no sheath voltage drops, and as such is similar to that of Reference 1. It can be seen from Figure 2 that the current concentrations are substantially less severe than the idealized theory predicts.

In order to estimate the effect of a current-dependent sheath potential on the current concentration, the inlet current distribution to an MHD channel was calculated[2], assuming a linear dependence of the sheath voltage on the normal current density of the electrode. The sheath effects greatly reduced the current concentration in much the same manner as indicated in these experimental results.

Therefore, the preliminary conclusion is that sheath effects are prominent in reducing the current concentrations in segmented electrode geometries. The results are encouraging in that they indicate that small-scale experiments can yield useful information on this problem. Further runs are planned at higher gas temperatures in both the equilibrium and nonequilibrium electrical conductivity regimes. In addition, possible modifications of the theoretical model to include sheath effects will be explored.

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1. Hurwitz, H., Jr., R. W. Kilb and G. W. Sutton: "Influence of Tensor Conductivity on Current Distribution in an MHD Generator," J.A.P. 32, 205, 1961.

2. Rogers, J. W.: "A Theoretical Investigation of the Inlet Current Distribution in an MHD Channel," E.A.A. Thesis, M.I.T. 1964.
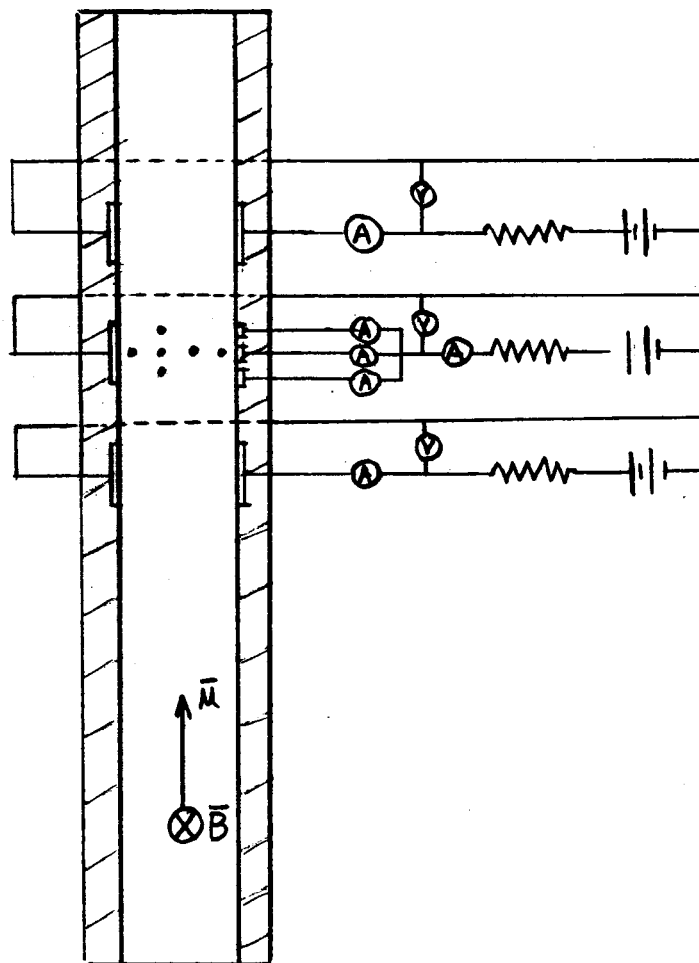
Fig. 1 - Test Section II and Schematic
of Circuit for Three Electrode Pairs

Run II-E $T_g \approx 1500\,°K$; $p_g \approx 1\,atm.$
$n_A/n_{TOT} = .90$
$n_{N_2}/n_{TOT} = .09$
$n_K/n_{TOT} = .01$
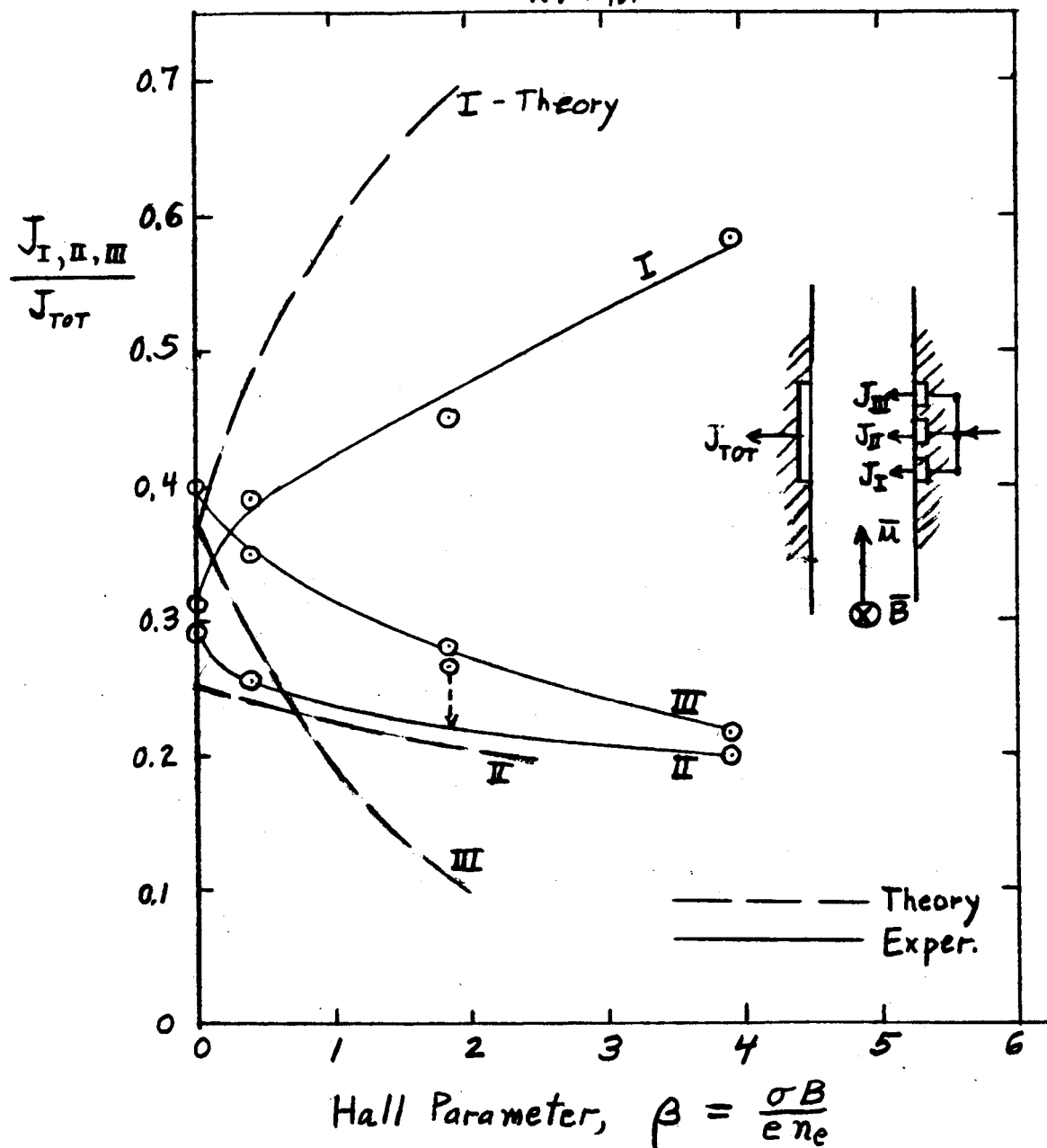
Fig. 2 - Current Distribution on Center Electrode Pair

SHEAR FLOWS

Investigators: E. L. Mollo-Christensen, F. K. Browand
Project No.:   DSR 9839

The objective is to investigate experimentally the stability of
shear flows.

Couette Flow Stability

The investigation of the stability of rectilinear Couette flow is
making slow but steady progress and will be completed in early
spring 1965. At that time, the apparatus will be used to examine
turbulence in the Couette flow channel. The large turbulent eddies
appear to be stationary in the laboratory frame for long periods of
time, and we will attempt to measure Lagrangian measures of turbu-
lence, such as the joint probability of relative acceleration of
labeled particles. This seems to be an important piece of informa-
tion, both for diffusion problems and in general for the dynamics
of turbulence. The information obtained would provide valuable
support for R. Kraichman's latest work on the theory of turbulence[1].

The experiments on stratified shear flow have been discontinued
until an interested student shows up.

Kelvin-Helmholz Instability of a Free Shear Layer

F. K. Browand has received support through this grant for continua-
tion of his investigation of instability and transition in a free
shear layer. The experiments have been completed and the results
are currently being written up as Mr. Browand's doctoral disserta-
tion.

The detailed development of the nonlinear disturbances in a free
shear layer, their spectra, amplitude distributions, phase velo-
cities and rates of change in the streamwise direction have been
described in detail, and a number of theoretical contributions made
to the understanding of such processes.

Three-Dimensional Disturbances in a Cylindrical Free Shear Layer

The existence of higher harmonics of the Benny-Lin waves in a cylin-
drical free shear layer was reported at the November meeting of the
Fluid Mechanics Division, APS[2].

Investigation of the Ekman Layer

In addition to the work mentioned above, an apparatus is under construction for investigation of the boundary layer in a rotating system, the Ekman layer. Quantitative observations will be made of the Ekman boundary layer for a range of Rossby numbers covering the parameters from the pure Prandtl boundary layer to the Ekman layer and observing the stability characteristics of such layers.

References

1. Kraichman, R.: Research Report No. 7, Task NR 062-309, Contract Nour 4307(00), July 1964.

2. Mollo-Christensen, E. L. and J. F. Stocky: Evidence of Streamwise Vorticity in a Cylindrical Free Shear Layer, Paper D4, November 1964.

GASEOUS NUCLEAR ROCKETS

Investigators: J. L. Kerrebrock, S. Chinnaswamy
Project No.:   DSR 9840

The immediate research objective of this project is tu assess the feasibility of containment (or separation) of gases in high-strength vortex flows. In the absence of a satisfactory theory for the three-dimensional flow in such vortices, we have chosen to study their properties experimentally. We have attempted to determine the influence of the geometrical parameters of the vortex on the connection between the tangential Mach number and the radial Reynolds number.

In particular, we have studied the effect of the length-to-diameter ratio of the vortex, since this parameter had not been varied previously, and since both theory and previous experiments have suggested that much of the loss in such vortices is due to friction on the end walls of the vortex channels.

As expected, we find that for a given radial Reynolds number, the peak tangential Mach number increases almost linearly with increasing length-to-diameter ratio, for values of the ratio up to about 20.

The Mach number then, however, decreases rapidly as the length is further increased. This was not expected, but perhaps should have been. We believe the decrease is due to restriction of the flow through the exhaust hole at the end of the vortex, due to the strong vortex motion. The radial pressure gradient of the vortex is so great that appreciable mass flow through the nozzle occurs only in a narrow annulus near the wall. This appears to be a basic limitation on the permissible length-to-diameter ratio of vortex tubes.

With the (optimum) length-to-diameter ratio of 20, the maximum tangential Mach number is near unity, and this may be sufficient to give some gas separation. We are presently assessing this possibility theoretically.

In addition, we have attempted to increase the permissible length-to-diameter ratio, and hence the tangential velocity, by providing exit nozzles in both ends of the vortex tube. If our present understanding is correct, this should result in a supersonic tangential Mach number. These experiments are being conducted currently.

It appears that we are close to realizing our stated objective. If it is concluded that vortex containment should be feasible, gas separation experiments will be initiated. If not, the study of vortex containment will be terminated.

AN INVESTIGATION OF FREE-MOLECULE FLOW FIELDS

Investigators: R. E. Stickney, R. Keating, S. Yamamoto
Project No.:   DSR 9841

Introduction

The primary objective of this work is to study the flow fields of
gases at extremely low pressures. Of particular interest are the
flow fields associated with:

1. Gases ejected from bodies in space

2. High-altitude flight

3. Vacuum pumps and systens

These three problem areas are closely related due to their common
dependence on kinetic theory and on high-vacuum techniques. Funda-
mental investigations which are relevant to all three problems have
been selected for the present research program.

Orifice Flow

An apparatus has been constructed for investigations of flow through
a sharp-edged orifice in the transition regime between the free-
molecule and continuum limits. A brief summary of the preliminary
results is presented below; a more detailed description of this work
is given in a recent S.M. thesis by W. J. Hastings.[1]

Since the apparatus was described in a previous progress report,[2]
it suffices here to say that the flow field of cesium vapor effusing
from an orifice was determined by employing a surface ionization
detector. The intensity of the flow at various angles from the
orifice centerline was measured over a range of Knudsen numbers.
(The Knudsen number is defined here as the ratio λ/D, where λ is the
mean-free-path of the cesium vapor upstream of the orifice, and D is
the diameter of the orifice.)

A polar plot of preliminary results for Knudsen numbers (Kn) of 46.7,
1.20, and 0.71 is shown in Figure 1. In the case of Kn = 46.7, one
would expect that the flow could be represented accurately by the
simple cosine law of effusion;[3] that this is not found in the present
experiment is due, most likely, to the finite thickness of the lips
of the orifice. (The diameter and thickness of the orifice are
0.0084 and 0.003 inches, respectively.) Although this effect has
been treated analytically by Clausing[4] and DeMarcus,[5] we plan to avoid
this complication in the future by employing thinner orifices.

As the Knudsen number decreases, we would expect a transition from the cosine pattern of free molecule flow to the "directed jet" associated with continuum flow. This trend is illustrated by the results for Kn = 1.20 and Kn =.0.71 in Figure 1. We are now attempting to explain this characteristic of the flow using kinetic theory. It is believed that the primary feature is the fact that the density of the gas immediately upstream of the orifice is lowest along the center line ($\theta = 0$), the result being that more molecules can effuse along the centerline because of the increased mean-free-path.

We are now attempting to increase both the range and the accuracy of the experimental data. In addition to this, equipment for measuring the velocity distribution of the effusing stream is being developed.

Diffusion Pumps and Ejectors

A complete theory of the operation of the diffusion pump and the vacuum ejector has not yet been developed. Throughout the past 50 years there has been a continual controversy regarding the principal pumping mechanisms of these devices. We have completed an extensive survey of literature pertaining to the diffusion pump, and have translated a Russian paper[6] which appears to be one of the most thorough studies in this area. Based on the existing literature and the results of our qualitative analyses, it is concluded that the pumping mechanisms depend most strongly on the characteristics of the flow field of the jet. Therefore, we have decided to concentrate our efforts on this problem as discussed in the previous section above.

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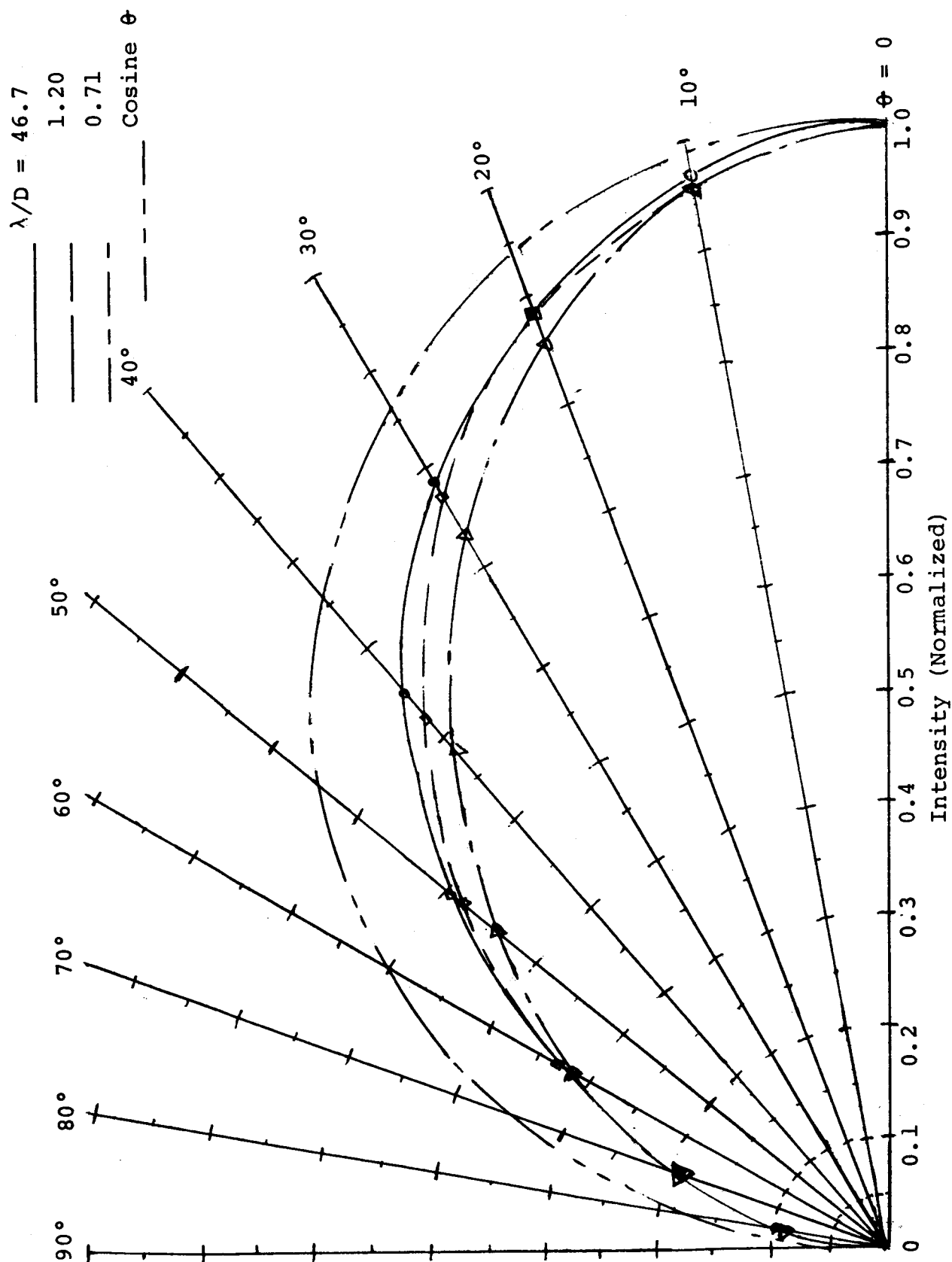
FIGURE 1. Polar Plot of Intensity vs. Angle

SUPERSONIC COMBUSTION WITH AND WITHOUT ELECTROMAGNETIC EFFECTS

Investigators: T. Y. Toong, J. B. McVey, R. Alpert, S. B. Lee
Project No.:   DSR 9842

The fluid mechanic-chemical kinetic interactions which permit the existence of chemical reaction rates of sufficient magnitude to produce self-sustained supersonic combustion waves are under investigation. Emphasis has thus far been placed on the construction of an experimental apparatus in which these interactions, which are of an oscillatory nature resulting from flow instabilities and accoustic effects, can be studied by means of spark shadowgraph and schlieren photography. The apparatus consists of a ballistic range in which projectiles can be launched at speeds up to 8000 feet/second into an instrumented test section filled with a combustible mixture.

Construction of the major components of the test facility has been completed. Installation of the instrumentation is proceeding with emphasis being placed on the electronics system. This will be followed by installation of the high-quality optical system. Concurrently with the instrumentation work, the range is being operated as a detonation tube to check the structural integrity of the system and to investigate the instrumentation problems associated with the utilization of various fuel-oxidizer combinations.

In its current configuration the range is capable of producing single-spark shadowgraphs with light from a point source passing into and out of the test section through plexiglass windows. Ultimately, high-quality schlieren photographs will be produced by utilizing a single internally-mounted spherically-ground mirror. Since the quality of these photographs is dependent on the preservation of the optical surface of the mirror, tests are being carried out to determine the effects of detonating gas mixtures on such surfaces. For these tests, the range is being operated as a detonation tube with conventional spark ignition. Stoichiometric mixtures of acetylene and oxygen at pressures ranging from 25 to 60 mm. Hg have been used. Thus far after approximately 25 runs, no erosive effects on the glass surfaces have been observed; however, objectionable deposits of combustion products, likely carbon, have been noted. These deposits may be characteristic of all hydrocarbon fuels and thus attempts will be made to carry out experiments with other detonable mixtures such as $NH_3 - O_2$ and $H_2 - O_2$.

The current tests have indicated that provisions for mixing and transferring the combustion gases to the test section are satisfactory and that the general structural design of the test section is sound.

The electronics system required for the synchronization of the photographic system with the flight of the projectile is currently being checked out. The initial event sensed is the passage of the projectile through a light beam produced by focusing the image of a ribbon filament lamp at the center of the line of flight. The image is then refocused on a photomultiplier tube which transmits a signal to a Tektronix 555 oscilloscope which acts as the basic timing device. Operation of the light screen will be satisfactory if the light reaching the photomultiplier is dominated by the lamp emission as opposed to emission from combustion products. Tests with the $C_2H_2 - O_2$ gases indicate that combustion product emission may dominate unless a satisfactory filtering arrangement is devised. Highly luminous detonation is characteristic of hydrocarbon fuels and this problem is expected to be less critical with other fuel-oxidizer combinations.

The electronic circuits required to form the triggering pulse for the spark light sources have been constructed and checked out. The submicrosecond time-delay unit which will be required to permit the taking of two schlieren photographs within a period of less than a full cycle of the flow oscillation will be based on a modification of a circuit currently being developed for use in the Lincoln Laboratory Re-entry Simulation Range.

The light sources to be utilized consist of a point source for the shadowgraph system and line sources for the schlieren system. The point source is a conventional design in which light from a spark discharge is transmitted through an annular anode. The line sources are of a new design in which a spark is discharged between tungsten filaments imbedded in a slot milled onto the face of a quartz block! This design produces a highly stable discharge which is necessary for high-quality schlieren work.

Since it is expected that under certain conditions fully-developed detonation waves will be generated in the test section, instrumentation to determine the character of these waves is being installed. A series of ionization gaps for measurement of the wave speed has been placed downstream of the photographic station. The ionization gaps and associated circuitry are of conventional design.[2] It is also planned to determine the level of instability or, equivalently, the spin mode by use of the "soot technique".[3] Preliminary tests of this technique have been carried out by inserting 0.015 inch thick vinyl sheets into the final two feet of the tube. A satisfactory soot coating has yet to be worked out.

It is anticipated that early in the next report period the projectile launching device will be fired and that photographs of the phenomena of interest will be obtained. It is then planned to place emphasis on an analysis of the flow instabilities so that an effective test program can be carried out.

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THE EFFECT OF AXIAL HEAT FLUX DISTRIBUTION

ON BURNOUT HEAT FLUX

Investigators: W. M. Rohsenow, P. Griffith, N. E. Todreas
Project No.:   DSR 9843

The objective of this program is to perform a systematic experimental and analytical investigation on the effect of nonuniform axial heat flux distribution on critical heat flux. This will permit the thermal limits of water-cooled reactor and nozzle systems, which inherently possess marked nonuniform operating efficiencies, to be correspondingly improved. The most important thermal limit of these systems is the so-called "burnout" or critical heat flux which is associated with the sharp reduction in ability to transfer heat from the heated surface. Since the conclusion from limited data of other investigators is that nonuniform heat flux distributions may lower the critical heat flux compared to uniform heat flux distributions, this program was undertaken as the stated objective indicates to attempt to delineate the effect of heat flux distribution.

Necessary modifications to an existing flow loop available in the Heat Transfer Laboratory of the Mechanical Engineering Department have been completed and initial calibration runs with uniformly heated test sections at the selected test conditions have been performed. Subsequent to this work, machining of test sections to yield nonuniform axial flux distributions was undertaken and is continuing on aluminum tubes. These flux distributions are achieved by electrical resistance heating of the wall of test sections which have been machined to dimensions yielding cosine, linear increasing and linear decreasing flux shapes. Of these test sections, cosine shapes of three degrees of truncation, and a limited number of linearly increasing shaped sections have been machined and tested in the available low-pressure loop facility.

From the data available on critical heat for these flux shapes, the following results are indicated. For given flow and inlet conditions, the total power input to yield burnout is approximately the same for the flux shape but may result from the fact that for the flux shapes tested, the dryout of the liquid film cooling the test section wall is achieved only by evaporation, whereas for other flux shapes which can be selected bubble nucleation may occur and accelerate the removal of the cooling liquid film.

Future work will aim at analytically predicting the achievement of the film dryout, i.e., burnout by (a) evaporation and (b) evaporation and nucleation, and at experimentally performing tests in which both these mechanisms are operative in causing burnout.

PROBLEMS IN RADIATIVE HEAT TRANSFER

Investigators: H. C. Hottel, A. F. Sarofim, W. H. Dalzell,
D. K. Sze

Project No.: DSR 9844

Scattering and Emission by Soot Particles

Studies of the mechanism of formation and burn-out of soot particles have been continued. These include the development of light scattering as a tool for measuring soot concentrations in hot combustion gases, the determination of the optical properties of soot, and the measurement of concentration and particle size distributions in a turbulent flame.

The light-scattering technique employed uses a curve-matching procedure to determine particle size. Monochromatic light scattered from a small volume (approximately 0.10" x 0.10" cylinder) is measured as a function of angle and compared to theoretical angular distribution curves for spherical particles (Mie Equations). Two methods, one involving fitting the entire angular distribution for both components of polarization and the other employing only the slope of the perpendicular component at an angle of 90°, give essentially the same average sphere size. Concentration is then determined by measuring the absolute intensity at one angle relative to the intensity of the incident beam.

Results of the light-scattering method have been checked by filtering soot particles from a hot gas stream of combustion products and comparing the mass concentration obtained this way to that obtained using the light-scattering system. Results of two runs are shown below.

Run	Average Part. Size	Part. Conc. $\frac{\text{Part.}}{\text{cc}}$	Mass. Conc. by Light Scat. (gm/cc)	$\frac{\text{Mass.conc.by filtration}}{\text{Mass.conc.by light scat.}}$
A	1660 Å	3.26×10^7	1.57×10^{-7}	1.70
B	1600 Å	2.80×10^7	1.19×10^{-7}	1.24

If it is postulated that the soot particles consist of many small (300-400 Å) particles plus a few large (1700 Å) particles, the mass concentration obtained by the two methods can be matched exactly.

The complex refractive index of soot was measured; first, to be used in the above technique for size and concentration determination and, second, to be used along with the soot mass concentration measurements to predict flame emissivities. A procedure was developed to press soot between two optically flat surfaces at 20 tons/inch^2 to form a smooth soot pellet. Reflectivity measurements were run on this pellet to find the index of refraction of the soot. For soot collected in the experiments used to check the mass concentration, the complex refractive index is:

$$m = 1.57 - 0.565i :$$

Since the value obtained by this method depends in part on the smoothness of the surface, the above value was checked several ways: The soot pellet gave the same index for two different rotations of the pellet relative to the incident light beam; an internal check in the method gave a check to within 4 percent; and the normal reflectivity measured, with an integrating sphere, checked the value calculated from the refractive index to about 3 percent.

The light-scattering technique was used to measure point-to-point concentration and particle size in a free turbulent diffusion flame burning C_2H_2 in air. For this experiment, the phototube output was passed through a very sharp electrical filter-amplifier to obtain a significant signal relative to the bright flame background emission. Particle sizes ranged between 1600 and 2100 Å diameter. (For any one run the particle size was approximately independent of position within the flame.) Particle concentrations varied between 16×10^7 and 0.4×10^7 particles/cc depending on both the position in the flame and the inlet fuel velocity. These data indicate that individual soot particles burn out very rapidly and, consequently, their burnout rate and kinetics are difficult to follow in a turbulent diffusion flame.

Particle Cloud Radiation in Rocket Systems

Development of calculational techniques for the prediction of the radiative flux from particle clouds such as hot rocket combustion products has been continued. Previous studies of radiative transfer in scattering media have usually been concerned with problems restricted to a unidimensional geometry, isotropic scatter, and nonemitting media. Most of the calculational techniques available are either too approximate or too complicated for application to practical situations. Consequently, the objective of the first stage of the present study is development of alternative methods to solve the one-dimensional transfer equation, for both isotropic and anisotropic scattering, in media within which the temperature profile is specified or which are in local radiative equilibrium.

A series solution is proposed. The one-dimensional transfer equation for isotropic scattering is

$$\mu \frac{dI}{d\tau} = I - K(\tau) - \frac{\omega}{2} \int_{-1}^{1} I d\mu$$

in which I is the intensity of the radiation, μ is the cosine of the angle made with the principal axis, ω is the ratio of the scatter and total attenuation coefficients, τ is the optical distance in mean free paths from the surface of the medium, and $K(\tau)$ is a term representing emission dependent on the local temperature. The last term in the equation is the radiation scattered in the direction of propagation of the beam under consideration. This last term is a continuous function of τ which should be expressible to a good approximation by the power series

$$\sum_{i=0}^{n} A_i \tau^i$$

For the case in which

$$K(\tau) = \sum_{j=0}^{n} B_j \tau^j$$

the equation of transfer becomes

$$\mu \frac{dI}{d\tau} = I - \sum B_j \tau^j - \sum A_i \tau^i$$

This first order linear differential equation may be solved for I. The result is

$$I = (A_0 + B_0) + (A_1 + B_1)(\tau + \mu) + (A_2 + B_2)(\tau^2 + 2\mu\tau + 2\mu^2)$$

$$\dots + (A_k + B_k)(\tau^k + k\tau^{k-1}\mu + k(k-1)\tau^{k-2}\mu^2 + \dots + k!\mu^k)$$

$$\dots + Ce^{\tau/\mu}$$

The integration constant C can be determined from the values of the intensities $I_+(0)$ and $I_-(\tau_o)$ of radiation incident on the boundaries ($\tau = 0$ and τ_o) of the medium. A positive (negative) sign indicates propagation in a direction of increasing (decreasing) τ. By definition

$$\frac{\omega}{2} \int_{-1}^{0} I_- d\mu + \frac{\omega}{2} \int_{0}^{1} I_+ d\mu = \sum_{i=0}^{n} A_i \tau^i$$

This results in an equation with a power series of τ on one side equalling a mixture of different order of exponential integrals with τ as parameter on the other side. For a specified τ, this forms a linear algebraic equation with A_i's as unknowns. If n+1 different values of τ are chosen, n+1 first order, linear, simultaneous algebraic equations are formed which can be solved for the (n+1)A_i's. An approximate solution to the equation of transfer is thus obtained.

In order to test the validity of this method, the equation of transfer was solved for a nonemitting medium [K (τ) = 0] having an optical thickness (τ_o) of one for the case of unidimensional incident radiation. The results were compared with Chandrasekhar's exact solution, and Churchill's two flux and six flux methods. Five terms (n=4) were used in the series expansion of the scatter term. The resulting solution for the integrated surface reflectance is

$$R = 0.64277 - 0.42726e^{-0.2/\mu_o} + 0.28231e^{-0.4/\mu_o}$$
$$+ 0.27079e^{-0.6/\mu_o} - 0.77874e^{-0.8/\mu_o}$$

where μ_o is the cosine of angle made by the incident beam with the surface normal. This solution gives much better agreement with the exact solution than that given by either the four or six flux methods.

FUEL CELL DEVELOPMENTS FOR SPACE POWER

Investigators: H. P. Meissner, M. C. Diebert, S. Paradis,
                  S. Schultze, P. Heinzer, A. S. Gendron
Project No.:   DSR 9845

The term "mixed feed flow electrode" is used here to designate a flooded porous electrode through which an electrolyte containing both fuel and oxidant is caused to flow. In a cell operating perfectly with mixed feed, the electrodes would be sufficiently selective so that the fuel would react only at the anode, and the oxidant only at the cathode. If desired, a single large cell could be constructed by making a stack of alternate anodes and cathodes, and connecting all the anodes in parallel, and all the cathodes in parallel. After the electrolyte-containing fuel and oxidant has passed through this stack, products of combustion would be removed, fresh fuel and oxidant added, and the enriched electrolyte would be recycled to the cell. Cell structure and cell cooling would obviously be simplified with this approach.

It was pointed out in the preceding report that electrodes had been found which operate with at least some success in a mixed feed system of hydrazine and peroxide. That is, the experimental current-voltage curves for the mixed feed system corresponded closely to those predicted from the voltage-current curves when flowing only hydrazine-containing electrolyte, or oxygen-containing electrolyte, through these electrodes. Selective electrodes can also be found for mixed flow cells operating on dissolved hydrogen and dissolved oxygen. Preliminary thought is being given to mixed flow methanol-oxidant systems.

It has been found that the Faradic efficiency of a mixed flow electrode is generally poorer than would be expected from its power output. That is, as pointed out in the report of last May, the "short circuit" current and the "external" currents can in theory be calculated for a mixed feed electrode from its performance when operating on electrolyte containing only oxidant, as well as on electrolyte containing only fuel. Thus, it would be expected that the consumption of fuel and oxidant would correspond to the sum of the internal and external currents. With hydrazine-peroxide, the total actual reagent consumption can be calculated from the volume and composition of the gases evolved at the electrodes. Depending on operating conditions, actual reagent consumption exceeds that corresponding to the sum of the external and internal currents by a factor of as high as 2. This factor is a function of variables such as current densities, flow velocities and of electrode composition, and the effect of these and other cell variables is under study.

Explanations of the behavior of electrodes in mixed feed flow systems are being sought. Several findings are striking:

1. A given electrode will show more strongly anodic behavior when the ratio of dissolved fuel to dissolved oxidant is high. Its behavior becomes more cathodic as this ratio becomes small.

2. Some types of electrodes tend to act as cathodes, others as anodes, in mixed flow systems. Thus silver electrodes have little tendency to act as anodes, regardless of the fuel-oxidant ratio, while platinum electrodes are strongly influenced by this ratio.

3. Certain electrode configurations are more subject to gas binding (that is, to blanketing by the evolved gases in a hydrazine-peroxide system) than others.

4. A totally submerged electrode shows a very sluggish voltage response to changes in electrolyte containing hydrogen and oxygen. The response is rapid for hydrazine-peroxide systems.

These and other findings are being investigated.

MICROWAVE INDUCED CHEMICAL REACTIONS

Investigators: H. S. Mickley, R. F. Baddour, L. D. Smullin,
                 P. Dundas, W. W. Cooper, N. F. Brockmeier,
                 A. Bell
Project No.:   DSR 9846

Introduction

The purpose of this research program is to use microwaves to induce chemical reactions which, in turn, yield desirable chemical end products. The effort has been concentrated in three areas: (1) a study of the probable mechanisms involved in microwave induced chemical reactions; (2) the design and construction of a suitable experimental setup for subjecting a chemical system to known levels of microwave irradiation and analyzing the reaction products and (3) actual chemical synthesis.

Equipment Changes

A movable probe together with associated equipment has been installed in the wave guide. This system permits measurement of standing wave ratios, electric field strength, and electron concentration. An attenuator which permits the microwave power to be varied over the range 50 to 1,000 watts has been designed and construction started. An elliptical high Q cavity has been designed to replace the cylindrical cavity used in earlier work. Construction of this cavity is well underway.

Hydrazine Synthesis

Further studies of the synthesis of hydrazine from ammonia have been made. The experimental difficulties which cast doubt on the early results were resolved. The equipment described in earlier reports was made vacuum tight and the chromatographic analysis technique perfected. It was possible to detect 0.1 percent hydrazine in the presence of ammonia and water vapor. Ammonia gas, at pressures ranging from 10 to 30 mm. of Hg, was passed through a cooled cavity irradiated with a 2,450 MC CW microwave discharge. The ammonia flow rate was varied from 10^{-5} to 10^{-3} moles per second, the power input ranged from 10^8 to 1.5×10^6 joules per mole. The effluent gases contained less than 0.1 percent hydrazine, 6 to 10 percent ammonia, and the remainder hydrogen and nitrogen. Runs were also made in which hydrazine vapor, pure or mixed with ammonia, was fed to the microwave irradiated cavity. The effluent gases contained less than 0.1 percent hydrazine. This is clear evidence that hydrazine, if formed from the ammonia, would be decomposed by the discharge under the operating conditions used. It is believed that

hydrazine is formed from ammonia when subjected to the microwave discharge but that the hydrazine is subsequently decomposed by the discharge. Presumably this can be overcome by using very short residence times.

Synthesis of Activated Hydrogen Atoms

Work on the synthesis of activated hydrogen atoms is continuing. The study is focussing on the mechanism involved with the aim of improving yields. The experimental work seeks to relate the electrical parameters (field strength, electron concentration) to hydrogen atom yield.

Synthesis of Chlorine

The synthesis of chlorine from hydrogen chloride by the Deacon reaction

$$2H\ Cl + 1/2\ O_2 \rightleftharpoons Cl_2 + H_2O$$
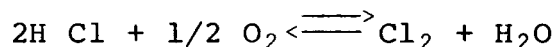
in the presence of a microwave field is being investigated. The experimental setup is nearly completed and preliminary tests are scheduled for December. This reaction is important for two reasons: (1) as a possible method for chlorine synthesis and (2) as a member of an important class of reactions whose reaction rate may be advantageously influenced by a microwave discharge. Although at room temperature the equilibrium yield of chlorine from the Deacon reaction is high, the rate at which the reaction proceeds is insignificant. Even with the best catalyst known, temperatures of 600° are needed to obtain reasonable reaction rates, and at these temperatures the equilibrium yield is greatly reduced. It is hoped that the microwave discharge will increase the reaction rate at temperatures which still provide attractive yields. If so, this technique will be applied to other reactions in this class.

ENVIRONMENTAL CONTROL

Investigators: E. R. Gilliland, L. B. Evans, R. H. Havlin
Project No.:   DSR 9847

The long-range objective of this research is the development for
environmental control of a simple, reliable system to remove acidic
gases such as carbon dioxide from the atmosphere and simultaneously
to resupply pure oxygen. Several systems have been considered in
which the carbon dioxide would be chemically adsorbed or absorbed
and from which the carbon dioxide could be regenerated in concentrated
form. If such a system is to operate satisfactorily, independent
of the surrounding gravity and temperature environments, the regen-
eration step should not depend upon direct application of heat as
is common with most conventional processes.

During the first year of this project, a study was made of systems
which involve the absorption of carbon dioxide in an aqueous solu-
tion of sodium hydroxide and sodium carbonate. The absorption step
of the process, which involves chemical reaction to form carbonate
and bicarbonate ions, is relatively well understood. Therefore,
the primary effort was devoted to the investigation of suitable
techniques for regenerating the system to recover carbon dioxide
in concentrated form from the spent solutions. The results indi-
cated promising possibilities for the technique of electrolytic
regeneration in cells utilizing ion-permeable membranes which
selectively permit transfer of either anion or cation to separate
regions of the cell. Oxygen is obtained in concentrated form from
the electrolysis of water.

A theoretical analysis was made of two types of electrolytic cell.
The first is based on transferring the carbonate and bicarbonate
ions through the selective ion-permeable membrane into a solution
of low pH which would release carbon dioxide. The second is based
on transferring the ions into a solution of high total concentration
which would also release carbon dioxide. The operation of these
cells is described in detail in the previous semiannual progress
report. The analysis indicated that, while both types of cell were
theoretically possible, fewer engineering problems would be expected
with the first type of cell. Accordingly, the program has been
directed toward studying initially the cell based on a difference
in pH.

At the end of the first year's work a simple cell based on difference
in pH had been constructed and operated. Measurements were made at
steady state of the voltage drop across the cell and the rates of
gas evolution from the cell as a function of the electric current
through the cell and the composition and concentration of solutions

being regenerated. While the preliminary experimental results demonstrated the technical feasibility of the process, an analysis of the data indicated the need for an extensive experimental program to obtain rate data necessary for optimization of the cell design.

In the initial months of the second year's work, a number of modifications were made in the experimental cell. These modifications were designed to enable more accurate, instantaneous measurement of the rates of gas evolution on a water-free basis. Provision was also made for measuring the separate voltage drops across individual compartments of the cell. A set of experiments to determine the effect on the cell performance of solution composition, solution concentration, voltage applied across the cell, and the spacing between compartments is currently in progress.

Based upon the results obtained, an analytical study will be undertaken to optimize the cell design. It is also planned to study the possibility of replacing the liquid absorbents with solid absorbents to make the cell independent of the gravity environment. In addition, it is proposed to investigate other possible systems for accomplishing the same end result.

NONLINEAR SYSTEMS THEORY

Investigators: G. Zames, R. W. Brockett, A. Spiridon
Project No.   DSR 9848

The broad object of this research has been to lay the foundations of a theory of nonlinear systems and circuits, using the mathematics of functional analysis. This year's research has been devoted mainly to the stability problem--the problem of relating the stability of a nonlinear, closed-loop, feedback system to the open-loop characteristics.

Our early investigations of the principle of contraction mappings have led to the discovery of a new stability theory, which differs from the classical method of Lyapunov and offers certain advantages over Lyapunov's method; in particular, input-output stability is established directly, without involving the notion of state. The contraction method has been applied to a variety of feedback and network problems.

Certain new criteria have been found for determining continuity and boundedness in nonlinear feedback loops. These criteria involve the factorization of the open loop into a pair of (incrementally) passive operators. These criteria are analogous to those in the linear theory that require the open-loop phase shift to lie between -180° and 180°. Applications have been made to loops containing one linear, time-invariant element, and one instantaneous non-linearity.

Similar criteria have also been obtained for feedback systems characterized by vector-differential equations, using the classical method of Lyapunov.

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NEUTRAL BEAM PRODUCTION

Investigator: L. M. Lidsky
Project No.:   DSR 9849

The original proposal (by A. E. Profio) was modified when
Professor Profio left MIT, and the equipment purchased
under the grant was transferred to Professor L. M. Lidsky.
The Duoplasmatron and its peripheral hardware will be used
in conjunction with a newly designed beam-handling system
to study the production of high-energy beams of neutral
atoms. The first experimental task will be the determina-
tion of the current of highly-excited neutrals and a
search for the conditions under which the number in the
upper excitation states is maximized. The neutral beam
will then be used for studies of electrostatic and electro-
magnetic (Lorentz) ionization and trapping in magnetic
fields. The ultimate goal is the production of a high-
energy trapped plasma in a "minimum-B" confining field.

The ion beam system has been designed and is presently
under construction. It is expected that the system will
be in use within one to two months. Time expenses incurred
during this period (technician and staff salaries, incidental
hardware, etc.) are being met by funds available for
research in plasma physics.

ANALYSIS OF REACTOR PHYSICS AND HEAT TRANSFER

IN NUCLEAR ROCKET REACTORS

Investigators: E. A. Mason, K. F. Hansen, W. W. Little, Jr.,
D. R. Mathews, R. W. Carlson
Project No.: DSR 9939

Work under this project has been concentrated on problems related
to nuclear rocket reactors. Two distinct areas of investigation
being studied are: start-up of rocket reactor cores, and rocket
reactor shielding.

The objective of the first portion was to investigate some of the
nucleonic problems associated with starting large, solid-core
nuclear rockets fueled with uranium-235. Primary emphasis was
placed on obtaining the reactivity variations during startup in-
duced by changes in hydrogen density and core temperature.

A detailed nucleonic analysis of a nuclear rocket during startup
would be extremely complex and time-consuming. In order to make
the problem tractable, the following procedure was adopted. First,
the material properties, such as core temperature, hydrogen density,
etc., were computed as a function of time during startup for a
specified power and flow-rate buildup. Using these time-dependent
properties, the reactivity variations during startup were calculated
using a diffusion theory model with 55 energy groups. The spatial
dimensions were approximated by assuming $\nabla^2 \phi(E) = -B^2 \phi(E)$. Such
an assumption should be permissible in light of the fact that changes
in core temperature and hydrogen density have little effect on the
spatial distribution, but have a significant effect on the energy
distribution.

It was found that large thermal nuclear rocket reactors (C/U = 2500)
are much more sensitive to changes in hydrogen density and core
temperature than small nuclear rockets (C/U = 250). The large
reactivity coefficients present in thermal reactors cause both large
($\sim$ -\$13.) and rapid ($\sim$ -\$1/sec) reactivity variations during the
quick startups contemplated for nuclear rockets. This problem can
be ameliorated to some degree by adding a nuclear poison to the core.
However, any poison has the adverse side effect of decreasing the
worth of an external control-rod system by decreasing the leakage.

An estimation of the worth of an external control-rod system was
obtained using a one-dimensional nucleonics model with three energy
groups. It was found that thermal reactors would require very thick
and heavy reflectors in order to control the reactivity variation
during startup.

In order to follow the reactor kinetic behavior two powerful numerical methods have been developed which are of quite general applicability. One method has the important property of being unconditionally stable while the other is stable for large reactivities (the converse of the usual numerical method). The basis of the methods is to assume the kinetic behavior may be approximated between time steps by an exponential function. In one case the frequency is characteristic of the asymptotic solution of the inhour formula, while for the other the instantaneous frequency is computed. In the case of constant reactivity, the asymptotic numerical solution is, in fact, the asymptotic eigensolution of the differential kinetics equation from which the stability may be proved and expressions for the truncation error derived.

The startup changes in a rocket reactor may be limited by thermal stresses and fuel temperature in the core. Work is just beginning on a space-dependent reactor model to study the effects of the rate of power increase, coolant inlet conditions, coolant flow rate, and propellant passage geometry upon the core temperature and thermal stress profiles.

Work on rocket reactor shielding is just beginning. The general objective in the shielding area is to investigate and develop methods of calculating the distribution in energy and direction of the radiation escaping from nuclear rocket reactor core and reflector regions in a form suitable for use in shielding calculations. This is important because the shield weight may amount to 50 percent or more of the total nuclear rocket engine weight, and the shield design depends critically upon an accurate knowledge of the radiation incident upon the shield from the reactor.

A formulation of particle transport using reflection and transmission probabilities known as "invariant imbedding" was chosen for further investigation and development because it leads to equations in which the independent variable is the material thickness so that the complete solution of a single problem yields transmission and reflection probabilities for all possible thicknesses of that material.

Work during this report period was mainly on the development of the invariant imbedding technique with some time spent in literature review and search for pertinent experimental shielding data.

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2. Little, W. W., Jr. E. A. Mason and K. F. Hansen: "Reactivity Variation During Startup in Nuclear Rockets," Am. Nuc. Soc. Trans. 7, 2 (Nov. 1964).

3. Hansen, K. F., B. V. Koen and W. W. Little, Jr.: "Stable Numerical Solution of the Reactor Kinetics Equations," Nuc. Sci. & Eng. (to be published).

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DIRECT ENERGY CONVERSION FROM RADIOISOTOPE POWER SOURCES

Investigators: G. L. Brownell, F. J. Mahoney
Project No.:   DSR 9940

In the application of ionizing radiation to the production of electrical power, schemes which may achieve this result without an intermediate step of heat formation are especially attractive because of their potentially high efficiency. At the present time one of the most interesting approaches of this type envisions the use of an electrostatic device to extract energy by passing appropriately chosen charged particles through a retarding electric field. Because of limitations imposed by practical operating conditions, low-energy beta radiation seems especially promising (i.e., energies less than approximately 250 kev.) Since beta radiation has a continuous energy spectrum rather than being monoenergetic, the originally envisioned diode-type electrostatic device would have to be modified to a multi-gridded device in order to extract energy most efficiently.

At the present time the actual number and potential distribution of the grids needed is under consideration. In this context, it is essential to obtain reliable data on the spectrum of beta radiation emitted from source configurations of interest. In essence we must determine the shape and angular distribution of beta radiation as a function of source thickness and composition as well as thickness and atomic number of source-backing material. Most of our work in the recent past has been devoted to the investigation and development of a comparatively inexpensive yet satisfactory beta spectrometer. In this regard we have achieved good results utilizing plastic scintillation crystals in conjunction with appropriate electronic pulse-analyzing equipment.

In the past this approach to beta spectrometry has been employed with high-energy (> 1 Mev) beta radiation with satisfactory results. However, not a great deal of work of this type has been done with beta energies of interest to us. Part of the reason for this state of affairs was the fear that plastic crystals were sufficiently non-linear in response at energies below about 200 kev that their use in a spectrometer was questionable. Tentative results from our investigations have failed to substantiate such fears.

At the present time it appears that the major problem in the use of plastic scintillation crystals in spectrometers is their comparatively poor energy resolution properties. To improve this situation, two lines of attack are being employed.

Since a major source of poor energy resolution is the comparatively high backscatter cross section for beta radiation incident on a plastic crystal, it has been found advantageous to impinge the incident beta radiation into a truncated conical well in the detecting crystal rather than onto a flat crystal face. In this way, radiation backscattered from the base of the truncated conical well will very likely impinge on another surface of the crystal rather than backscatter away from the crystal.

To further improve energy resolution we are in the process of writing a computer code for correcting output data from the spectrometer by employing various so-called energy resolution functions (i.e., functions which describe the probability that an electron of energy E_0 appears in the spectrometer readout to have an energy in the interval E to E + dE). This approach attempts to cover by one comparatively simple function all the various sources of poor energy resolution.

TEXTURE HARDENING

Investigators: W. A. Backofen, S. W. Zehr
Project No.: DSR 9941

Emphasis in the last period has been placed on the relationship of texture to fatigue crack nucleation and growth. Tests have now been made in which speciments were subjected to fully reversed 4-point bending at a frequency of about 10 cycles per second; although some information about the fatigue process has resulted, the principal gain from this first group of tests was certain structural refinements in the machine and an improved specimen design. A reasonably satisfactory technique for electropolishing the gauge section of the specimens has also been developed.

Comparisons of the fatigue behavior for different materials are much more meaningful if based on a common plastic-strain amplitude for all. To allow such comparisons, different methods have been examined for determining the plastic strain amplitude in testing. At the moment, the most promising appears to be one based on the use of post-yield strain gauges attached to representative specimens.

Materials tested to date have been the HCP (α) titanium alloys of 5Al-2.5Sn and 4Al-1/4O$_2$ in sheet form. The textures of both consist of strong basal-plane alignments parallel to the sheet surface, with some transverse spreading. The 4Al-1/4 O$_2$ alloy is the more sharply textured. The arguments for choosing such textures were given in the previous report. Recently, a specially processed quantity of the titanium 6Al-4V ($\alpha + \beta$) alloy was acquired for future testing.

Observations made thus far have come from specimens oriented with the rolling plane in the maximum fiber-stress surface. It was interesting to find much more topographical development on the sides of such specimens, despite the stress gradient there, and considerable cracking that appeared to nucleate at those surfaces. The finding is consistent with the earlier suggestion that the orientation of primary directions will influence the topographical change associated with crack nucleation. More specifically, if the most highly stressed and potentially most active directions are oriented so as to lie in a surface, the contribution to cracking in that surface should be much reduced. In these experiments it appeared that the nominally less-favored "side" surfaces were much more involved in the cracking event because of this circumstance.

Progress has also been made in the construction of the combined-stress fatigue-testing unit intended for use in evaluating the direct texture-hardening contribution to fatigue resistance.

THE EFFECTS OF SPACE RADIATION ON ELECTRONIC MATERIALS

Investigators: M. B. Bever, P. Chaudhari
Project No.:   DSR 9942

This research is concerned with the investigation of the effects of radiation on materials of interest for their electronic properties. In the last report, the proposed measurements were outlined and the initial testing of the required equipment was described. During the current period, bismuth telluride was irradiated with protons for different times at room temperature. The Hall coefficient and resistivity were measured at different temperatures as functions of radiation dosage. Line shifts and broadening of x-ray diffraction peaks of irradiated single crystal foils of bismuth telluride are being investigated at present. A technique has been developed for preparing very thin specimens of bismuth telluride.

Irradiation

A specimen of a single crystal of p-type bismuth telluride was irradiated with 7.5 Mev protons. The times ranged from 2 to 9 hours and the integrated doses from 1.5 to 8.0 x 10^{16} protons/cm^2. The specimen had a thickness of 0.1 cm, which was appreciably larger than the estimated range of 0.01 cm of the radiation used. This specimen is designated Specimen A.

Two single-crystal foils, 0.002 and 0.009 cm thick, were also irradiated with 7.5 Mev protons. The integrated dose was 3.0 x 10^{16} protons/cm^2. These specimens are designated Specimens B-1 and B-2.

Hall Coefficient

The Hall coefficient was measured from 100° K to room temperature after various periods of holding at and below room temperature. The Hall coefficient of Specimen A was lower after than before irradiation over the entire temperature range of measurement. A further decrease occurred after holding for 60 hours at 78° K. This decrease was found over the entire temperature range of measurement. On further holding at room temperature for 24 hours, the Hall coefficient of Specimen A decreased again, but this decrease was found only at temperatures below 150° K; above this temperature of measurement the value was the same before and after the 24-hour holding period.

Resistivity

The resistivity of Specimen A measured from 100° K to room tempera-
ture increased with increasing dosage of irradiation. The resistivity
increased during the holding period of 60 hours at 78° K and decreased
during the 24-hour period at room temperature, although the final
value was higher than the value obtained after holding at 78° K.
These changes were found over the entire temperature range of measure-
ment.

Interpretation

A tentative interpretation of the foregoing results is that the
changes occurring at 78° K are due to the diffusion of hydrogen
(introduced by the proton irradiation) to those parts of the specimen
which were beyond the range of the incident protons. The changes
in the Hall effect and resistivity after holding at room temperature
is attributed to the formation of configurations of lower energy
by the defects.

X-ray Diffraction

Changes in the lattice parameter of Specimens B-1 and B-2 after irra-
diation are at present being measured by x-ray diffraction. A small
shift but no detectable broadening of the diffraction lines has been
found. The cell dimension in the c-direction (based on the hexagonal
system) decreased by less than 0.1 percent.

Preparation of Thin Specimens

The preparation of specimens thinner than the calculated range of
penetration is important for this investigation. Chemical etching
was unsuccessful as it caused pitting of the surface. Cleaving with
a small blade did not produce continuous plane surfaces, but satis-
factory specimens could be prepared by cleaving the bulk specimen
to approximately the desired thickness and then smoothing the surface
by removing isolated flakes with adhesive tape.

Plans for Future Work

Thin foils (0.002-0.010 cm thick) of bismuth telluride prepared by
the new technique will be irradiated for different times. Their
Hall coefficient and resistivity will be measured. More precise
x-ray diffraction measurements will be carried out.

Attempts will be made to prepare even thinner foils of bismuth tellu-
ride (500-700 A.U. thick) for high-resolution transmission electron
microscopy. If such foils can be prepared, they will be irradiated
and the resulting changes in structure will be investigated.

SURFACE BEHAVIOR OF SOME REFRACTORY SOLIDS WHEN

EXPOSED TO EXTREME VARIATIONS IN PRESSURE

Investigators: P. L. de Bruyn, A. F. Witt, J. Salamitou
Project No.:   DSR 9943

Introduction

In the second Semiannual Progress Report of June 1964, it has been
proposed to make adsorption and desorption measurements with the
help of gas-solid chromatography in order to evaluate the variation
in surface behavior as brought about by surface treatment and
changes in environment of solids. This investigation was initiated
with a study of the surface behavior of rutile. The particular
sample which is being studied at present is "titanox," a large
specific surface rutile obtained from Titanium Pigment Corporation.

In the previous report, it was noted that methanol vapor was a good
test gas for adsorption measurements on rutile because a reasonable
retention time, a sharp front, and a relatively steep tailing were
observed in the elution development technique. This progress
report records the detailed experimental technique used in obtain-
ing adsorption isotherms of methanol on rutile as well as some
preliminary adsorption results.

Apparatus

A rough sketch of the experimental apparatus was given in the pre-
vious report. Since this report was written, some modifications
were introduced and a diagram of the present apparatus is shown in
Figure 1. The adsorption column (6) and the thermal conductivity
cell (4) are situated in the thermostat (5) made of two transite
boxes, one inside the other with a 1-inch thick layer of glass wool
between them. The adsorption column consists of a three-stage
"U"-shaped pyrex column with decreasing diameter inside a vertical
cylinder. The temperature inside the box is obtained with a 1,000
watt electrical coil located at the bottom of the thermostat.
Uniform temperature is maintained by forced air circulation and is
controlled with a chromel-alumel thermocouple. - The deviation in
temperature from the bottom to the top of the column does not exceed
$\pm$ 0.5° C. The main part of the sample introduction device is the
saturator (7); it is a standard 70 cm condenser tube. In the inner
tube, the carrier gas helium passes through a fritted glass disc
and then flows through liquid methanol. The temperature of the
saturator is kept constant by circulating methanol vapor in the
outer tube. This vapor is generated in the boiling flask (11) and
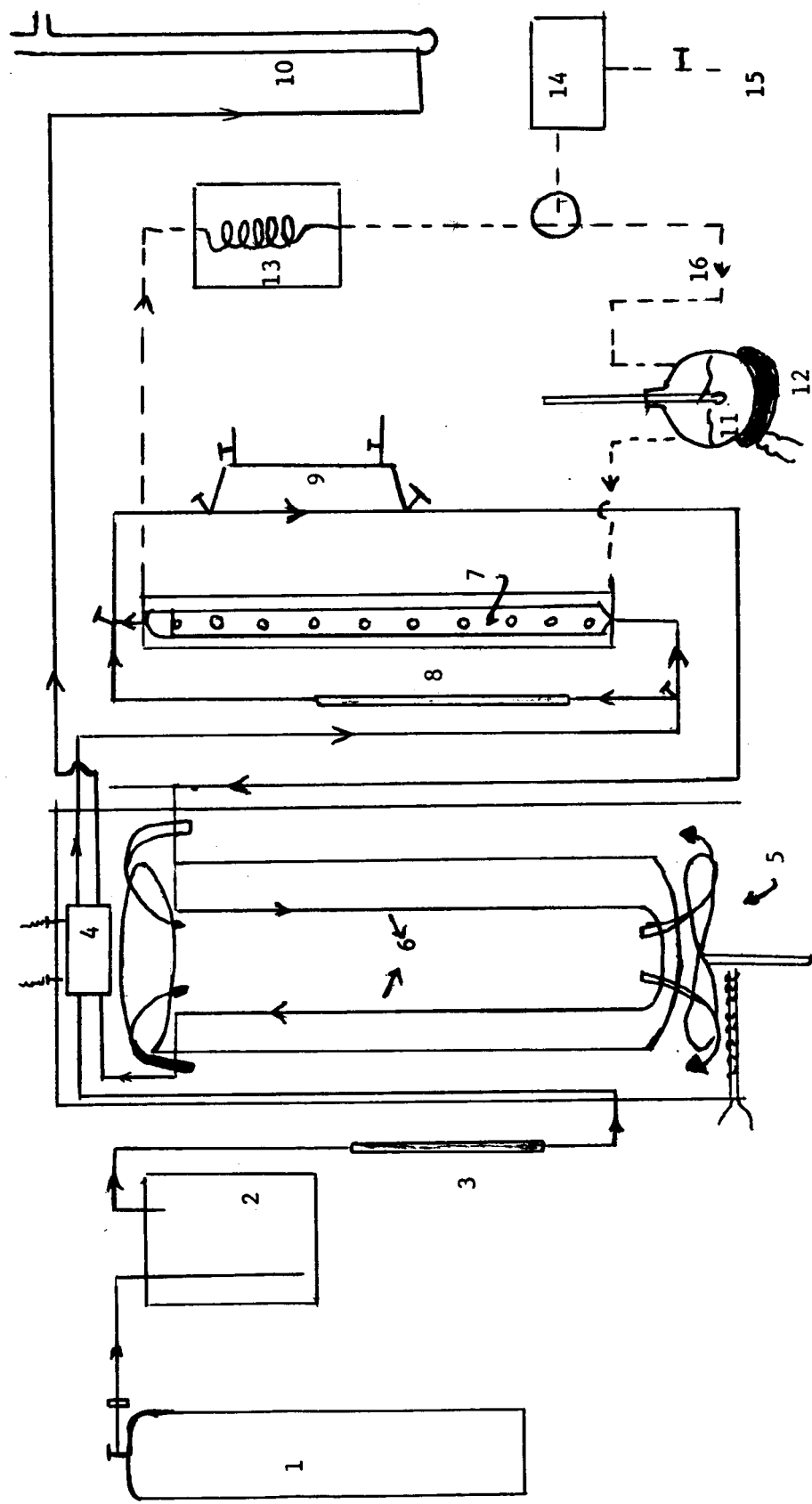
FIGURE 1. Sketch of Experimental Circuit.

1. Helium tank
2. Surge bottle
3. Capillary tube
4. Thermal conductivity cell
5. Thermostat
6. Adsorption column
7. Saturator
8. Capillary (by-pass)

9. Nitrogen introduction
10. Soap film flow meter
11. Flask with boiling methanol
12. Electric heater
13. Condenser (with dry ice)
14. Manostat (cartesian type)
15. Vacuum pump
16. Liquid plug

is condensed in the spiral cooled down by dry ice in acetone. The circuit is connected to a vacuum pump through a cartesian manostat. By means of this monostat, the boiling point of the methanol in (11) is controlled and in turn the temperature of the outer tube of the saturator, and finally the partial pressure of methanol in the gas stream exiting from the saturator. The base line or reference level on the chromatrogram is determined by the deviation of the cell when pure helium flows through it. Since this reference line is a function of the gas flow rate, it is important to keep the flow rate of gas entering the detection device constant regardless of whether the gas contains methanol or not. This is obtained by a by-pass capillary tube (8) the size of which has been computed and verified by experiments.

Experimental Procedure

In order to calculate the adsorption density, the true breakthrough time of methanol in the column must be known. It is, therefore, important to introduce an inert gas, inert with respect to adsorption on rutile at operating conditions, which furthermore should also have a thermal conductivity different from that of the carrier gas helium. Nitrogen was chosen as the inert gas and it is introduced as an impulse. The path followed by the gases in order to get a frontal analysis chromatogram are shown in Figure 2. With reference to this diagram, the following steps in the experimental procedure may be described:

1. The carrier gas follows paths II, IIIa by adjusting stopcocks R1, R2, R3, and R4. With this flow circuit, the base line at a given temperature and gas flow rate is established.

2. Next nitrogen is admitted through stopcock R5 which is in communication with a nitrogen tank.

3. Stopcock R5 is closed and stopcocks R1, R4, R3, R2 reversed in this order so that the gas now follows paths I and IIIb. The gas now contains nitrogen and methanol vapors with different exit times which will determine the real breakthrough time.

Experimental Results

A typical chromatogram is shown in Figure 3. Following Reilley, Hildebrand, and Ashley[1], the breakthrough time t_b, that is the distance of the nitrogen peak to the inflection point of the step curve, is taken at half the height of the plateau H. This parameter is not necessary for the determination of the adsorption isotherm but it gives an indication of the concentration of the vapor in the helium carrier gas at the exit of the chromatographic column and must, therefore, be reproducible under the same experimental conditions. Two series of experiments at the same temperature of 112° C have been conducted on 85 grams of titanox. The results obtained
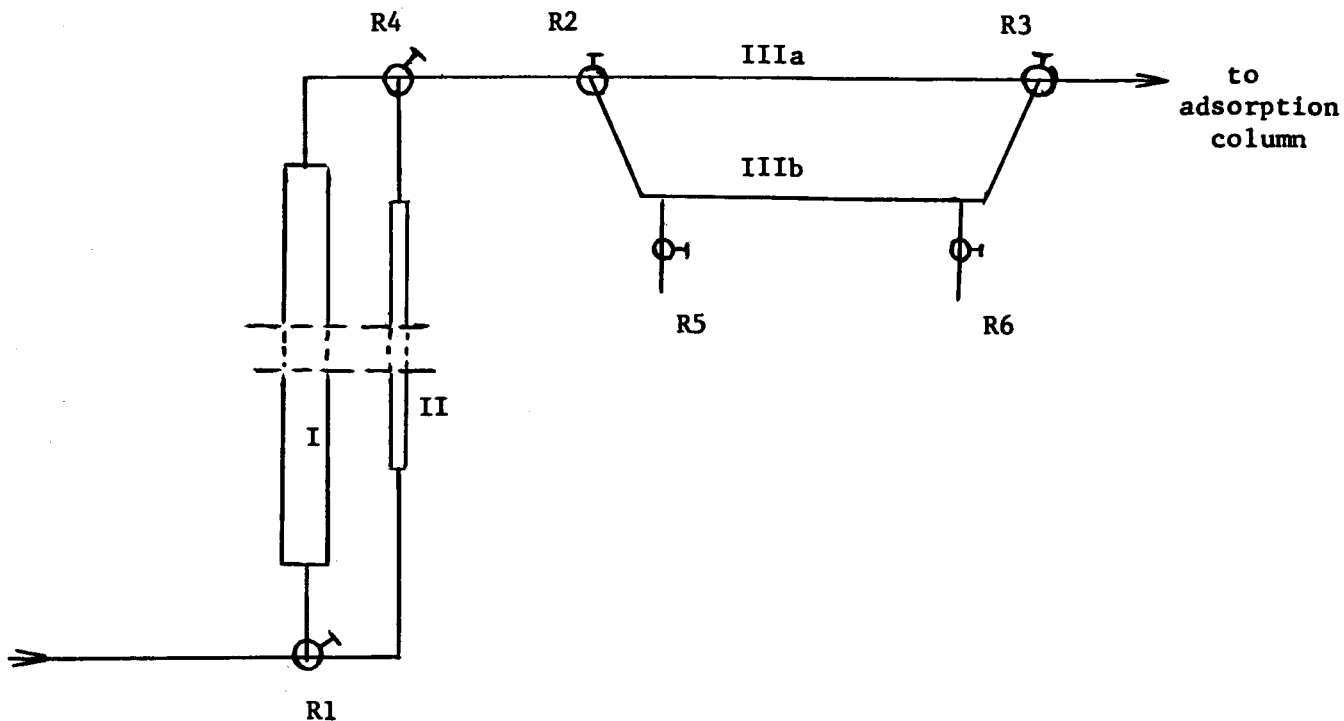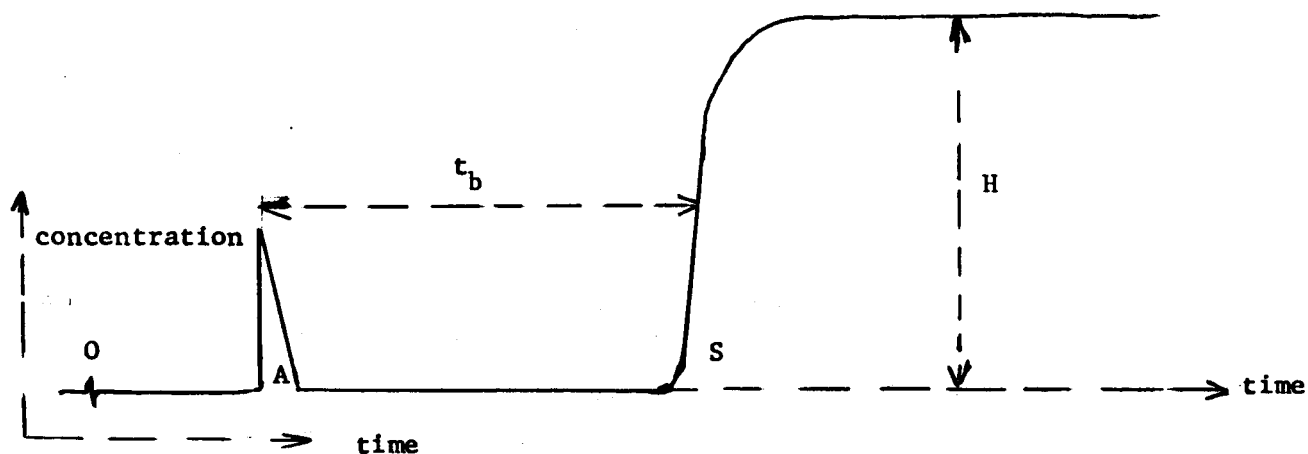
FIGURE 2. Sketch of the Alternative Paths
Followed by Gas Stream.

O   introduction

A   nitrogen peak

S   breakthrough of methanol

FIGURE 3. $\left(\begin{array}{l} \text{Speed of Recorder} \\ \text{2 inch/mm.} \end{array} \right)$

with these measurements are shown in Table I. It should be mentioned that, after the first series of experiments were run, pure helium gas was flowed through the column for quite awhile before the second series of tests were performed.

Calculation of Adsorption Density

In order to determine an adsorption isotherm, the equilibrium concentration of methanol vapor and the amount of vapor adsorbed must be known. The partial pressure of methanol in helium is determined by the average temperature of the saturator with the help of the following expression[2]:

$$\log P = \frac{0.05223}{T} a + b \qquad\qquad [1]$$

where

$$a = 38,334, \quad b = 8.8017$$

The volume (v) of methanol adsorbed per gram of column material can be obtained from a knowledge of the breakthrough time; the general expression for the amount adsorbed per gram is given by:

$$v = \frac{(\text{flow rate})(\text{vapor concentration})(\text{breakthrough time})}{\text{weight of adsorbent}} \qquad [2]$$

The concentration of methanol in the vapor phase is given by the ratio P/P_o where P_o = total pressure at exit and is equal to the atmospheric pressure. It is customary to make a correction for the pressure drop across the column. The expression given by Keulemans[3] for the average pressure in the column is:

$$\overline{P} = \frac{2}{3} P_o \frac{\left(\dfrac{P_i}{P_o}\right)^3 - 1}{\left(\dfrac{P_i}{P_o}\right)^2 - 1} \qquad\qquad [3]$$

where P_i is the total pressure at the entrance of the column. It is also necessary to make a correction for the temperature since the flow rate is measured at room temperature in the soap film flow meter. The complete expression for the amount adsorbed (v) is, therefore:

$$v = t_b \times r \times \frac{P}{P_o} \times \frac{T_c}{T_r} \times \frac{2}{3} \frac{\left(\dfrac{P_i}{P_o}\right)^3 - 1}{\left(\dfrac{P_i}{P_o}\right)^2 - 1} \times \frac{1}{g} \qquad\qquad [4]$$

In the experimental column, the pressure drop has been observed to be about 200 mm of mercury. This means that P_i/P_o is equal to

$$\frac{760 + 200}{760} = \frac{960}{760} < 1.5$$ and it is possible to make the approximation

$$\overline{P} = \frac{1}{2} (P_i + P_o) \qquad [5]$$

In view of Equation 5, Expression 4 may be simplified to give:

$$v = t_b \times r \times \frac{P}{P_o} \times \frac{T_c}{T_r} \times \frac{1}{2} \left(\frac{P_i + P_o}{P_o} \right) \times \frac{1}{g} \qquad [6]$$

where t_b = breakthrough time, r = flow rate, p = partial pressure of methanol, P_o = atmospheric pressure, P_i = pressure at the entrance of the column, T_c = column temperature, T_r = room temperature, g = weight of adsorbent. The calculated values of v as determined from Equation 6 are also given in Table I. The adsorption isotherm determined from results given in this table are shown in Figure 4.

At present, the discrepancy in the results of the two series of experiments are puzzling. Further study is in progress to resolve this difficulty. It is, however, believed that the results obtained in the second series are more reliable. It is also interesting to note that the adsorption density is proportional to the equilibrium pressure throughout the pressure range investigated.

References

1. Reilley, N., G. P. Hildebrand, and Z. W. Ashley: Anal. Chem. 34, 1198, 1962.

2. Handbook of Physics and Chemistry, 40th Edition.

3. Keulemans, A.: "Gas Chromatography," 2nd Edition (1959), Reinhold Publ. Corp.

FIGURE 4
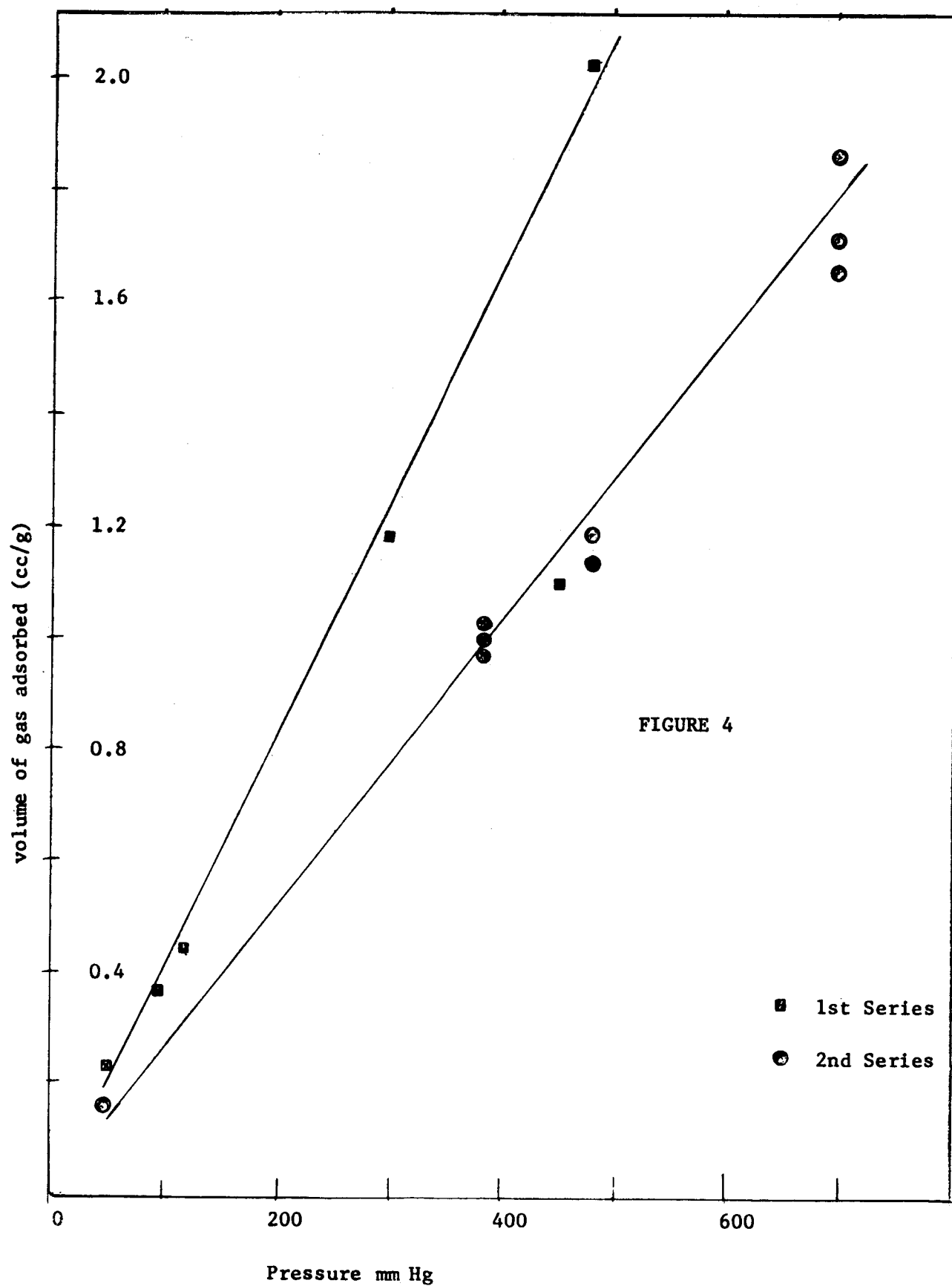
TABLE I

Adsorption Results at 112° C

Flow Rate of Exit Gas cc/min.	Breakthrough Time min.	Temperature at Saturator ° C	Partial Pressure of Methanol in Gas Stream mm Hg	Volume of Methanol Adsorbed cc/g
55	3.37	55	478	2.03
54	2.00	54	450	1.08
52	3.47	44	300	1.20
46	3.61	20	97.2	0.37
43	4.06	24	116	0.44
50	4.39	10	48	0.22

Second Series

53	2.12	62	700	1.64
53	1.99	62	700	1.71
53.5	1.86	62	700	1.86
54	2.04	54.2	480	1.14
53.5	2.11	54.2	480	1.18
53	2.00	54.2	480	1.12
53	2.01	54.2	480	1.13
53	2.18	49.2	385	0.97
53	2.05	49.2	385	1.02
44	3.66	5.9	45	0.16

THE DIFFUSION OF VOLATILE METALS THROUGH

NONVOLATILE MATERIAL AT LOW PRESSURES

Investigators: T. R. Meadowcroft, J. P. Cuny, J. Yarwood
Project No.: DSR 9944

The object of this research is to determine if the Knudsen effusion technique can be modified so as to provide a means for the measurement of diffusion coefficients of volatiles in nonvolatile systems. Much of the work to date has been in modifying a vacuum furnace and accessories for this work and in making preliminary runs to determine optimum operating conditions. This preliminary work has indicated the possibilities for this method as a substitute for the multiple analysis or radiometric techniques generally used for solid diffusion.

The technique used has been described in the First and Second Semiannual Progress Reports of the Center for Space Research. The Knudsen cell method is modified to measure a steady state diffusion flux and a chemical potential or activity gradient of the diffusing species. To relate activity to concentration gradients for substitution into Fick's first law, it was initially thought that the activity of manganese in iron could be assumed equal to concentration. This view was questioned, however, so the first study made was on the activity of manganese in the system Fe-Mn. Then measurements were made to ascertain the optimum conditions for diffusion measurements in Knudsen cells.

Results

Vapor pressure measurements have been made on a series of alloys with the compositions shown in Table I over a temperature range from 1070° to 1540° K. The vapor pressure of manganese in iron alloys as a function of temperature is shown in Figure 1. The results have been translated by means of free energy against temperature diagrams to show that the entropy of mixing for the system is ideal (S_{Mn}^M = -R ln x) and that the heat of mixing is small and negative. The results have been shown as activity versus atomic concentration at two temperatures in Figures 2 and 3. It is interesting to note that the activity approaches Raoultian behavior not only at high concentrations but also in the dilute solution range.

The activity results are of considerable interest in the diffusion work since alloys from 20 to 50 atomic percent manganese are used to fix the activity of manganese at one side of an iron foil. The

activity at the other side is measured by the Knudsen cell. As is shown in Figures 2 and 3, the activities in this region vary by roughly 25 percent from the concentration which is used in the diffusion equation.

Preliminary diffusion measurements have shown that the flux of manganese through an iron foil is primarily a function of the initial activity of manganese, the final activity at steady state being very small for even thin foil. In the simplified expression

$$\text{Flux} = -D \frac{\Delta C}{t}$$

this means that ΔC may be replaced by the base alloy composition. Since D is, however, a function of composition, a number of base alloys must be used to ascertain the form of D. Results obtained so far have been of the right order of magnitude but have had some considerable scatter. However, the technique is workable and more precise measurements are anticipated.

Program

In the next few months the equipment will be modified slightly to permit better control of temperature over long periods of time. A series of diffusion experiments will then be made to ascertain the precision and accuracy of the technique. Other binary systems with manganese will then be studied.

Thesis

Cuny, J. P.: "Diffusion Measurements Using a Knudsen Cell," S. M., 1964.

TABLE I

Composition of the Fe-Mn Alloys

Alloy Number	% Mn	% Fe
10	10.96	89.04
30	30.20	69.80
40	40.38	59.62
50	50.96	49.04
70	69.79	30.21
90	88.34	11.66
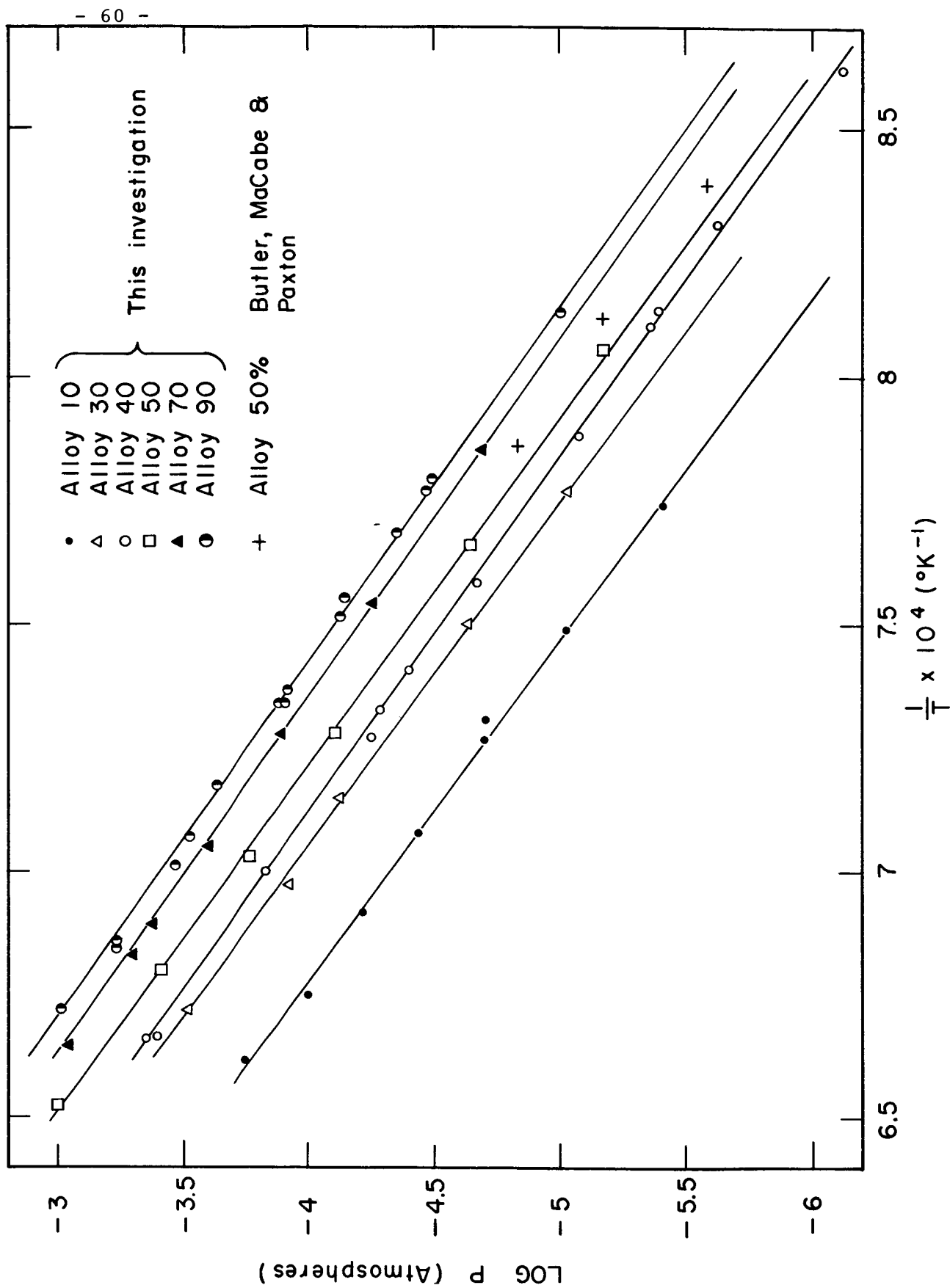
FIGURE 1. VAPOR PRESSURE OF Mn IN DIFFERENT FERRO ALLOYS AS A FUNCTION OF T.
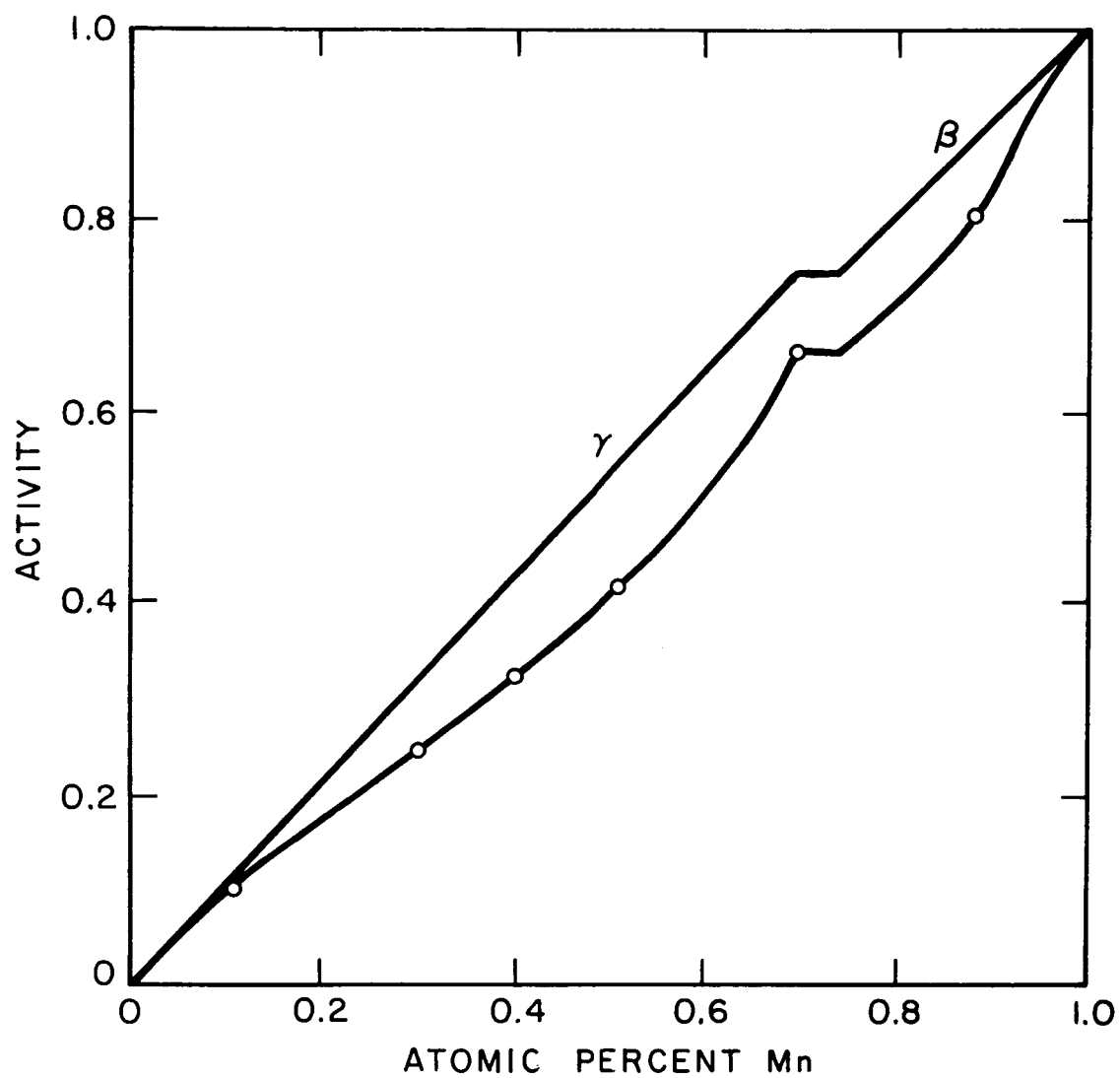
FIGURE 2   ACTIVITY OF MANGANESE AT 1300°K WITH
RESPECT TO BETA MANGANESE
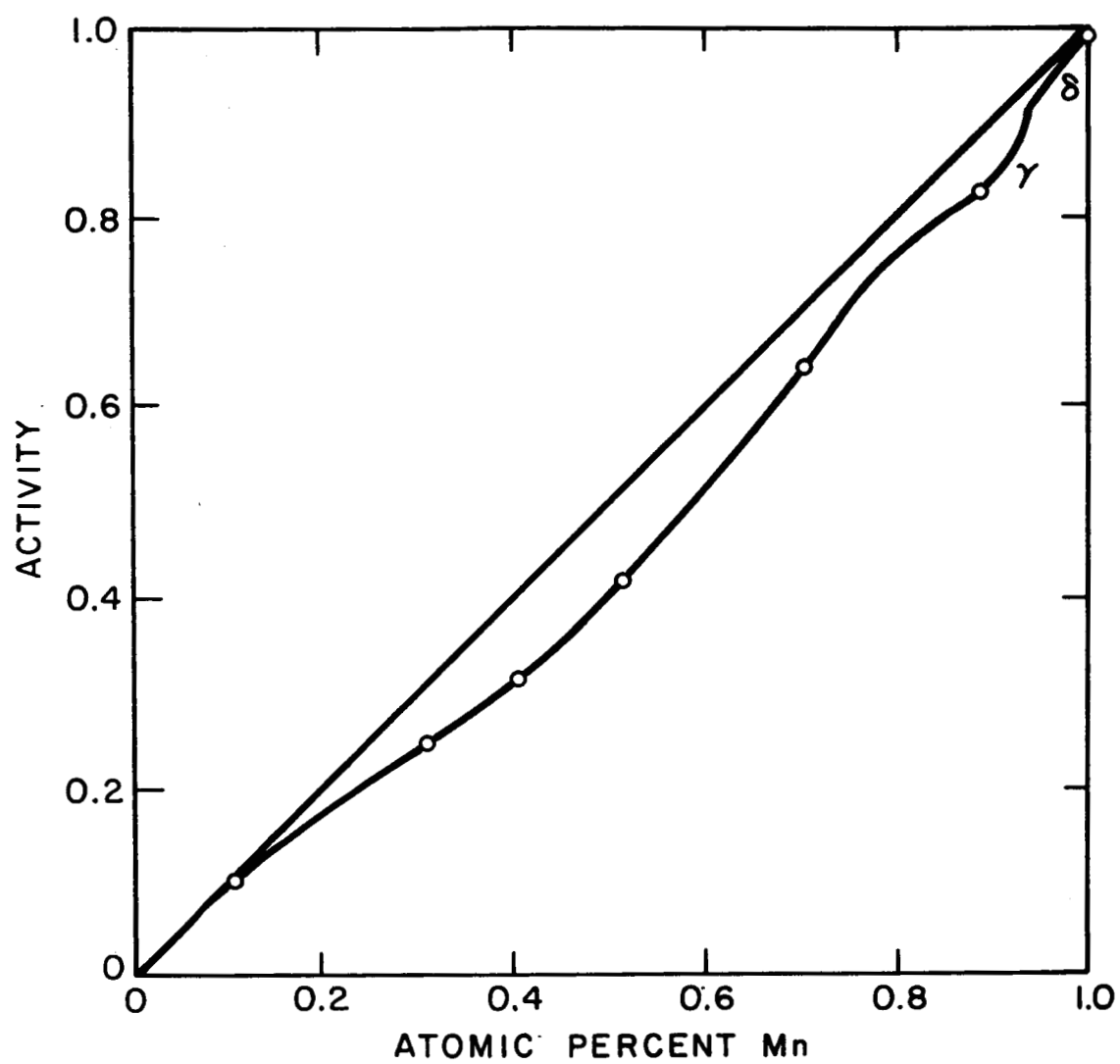
FIGURE 3   ACTIVITY OF MANGANESE AT 1450°K WITH
RESPECT TO GAMMA MANGANESE

DESIGN OF A LARGE FLOW RATE THERMAL PLASMA SOURCE

Investigator: G. C. Oates
Project No.   DSR 9945

The objective of the program covered by this grant was to design, in detail, a facility capable of supplying up to two kilograms per second of argon heated to approximately 2000° K stagnation temperature. It was planned to design the facility with a large enough heat capacity so that flow durations of approximately one minute would not seriously decrease the exit stagnation enthalpy.

Figure 1 shows the design drawing of the overall device. All internal parts of the heater, with the exception of several small boron nitride parts, are graphite. Insulation is provided by several layers of graphite felt backed up by three inches of graphite fibres. The seeding device indicated in the drawing consists of a variable-speed motor driving a ram which in turn drives a 200 cc surgical syringe. The resulting potassium flow will be vaporized by a 40 kw arc jet to emerge through the "seeder pipe" in a plenum chamber at the top of the heater.

At present, the pressure vessel and all of the internal parts of the heater have been ordered, as have most of the parts necessary for manifolding the argon supply and controlling the plasma flow. Delivery of the major parts is expected shortly, and construction and installation will follow immediately upon delivery of the parts.

GAS OUTLET

GAS INLET
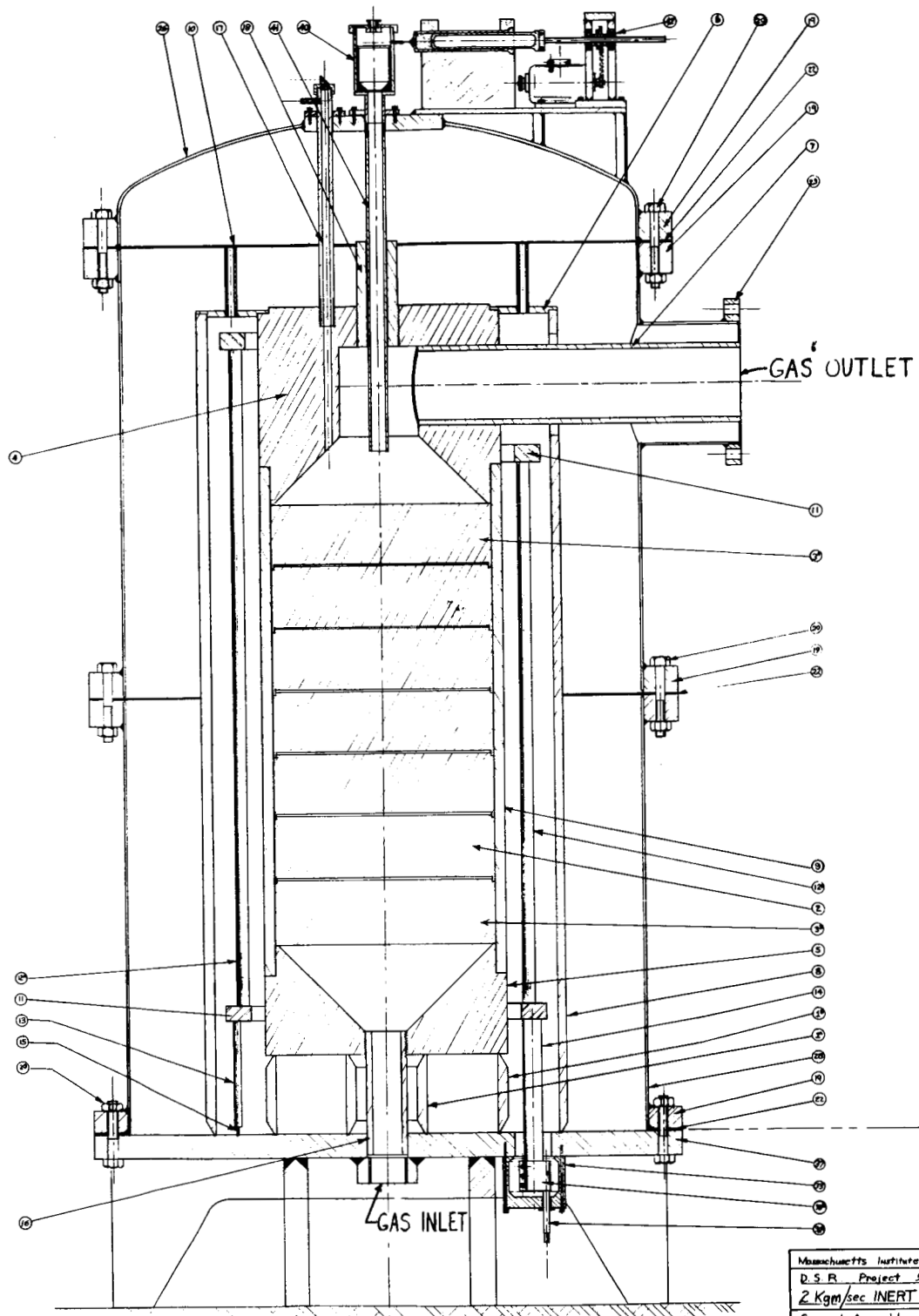
INERT GAS HEATER

Massachusetts Institute of Technology

D.S.R. Project 9945

2 Kgm/sec INERT GAS HEATER

General Assembly — 1/5 scale

Designed+Drawn: Dr. Gordon C. Oates
James P. Reilly
James L. Nash-Webber

July 1964

KINETIC THEORY OF PLASMAS

Investigators: J. E. McCune, P. Manglis, C. Bartlett
Project No.:   DSR 9946

A new approach to the study of irreversible behavior of plasmas
and the self-limiting of microinstabilities of plasma oscillations
has been initiated, utilizing an "N-momenta description" of plasma
dynamics. The first result of this study was the derivation of the
master equation for spatially-homogeneous plasmas without magnetic
field. This work has recently been published;[1] extensions and
applications to unstable plasmas are described in the following.

There are three main results of the initial study, aside from the
master equation itself:

   1. The proof of a "weak" H-theorem for spatially-homogeneous
   plasmas, showing that the generalized correlations* always
   (eventually) drive the system toward equilibrium;

   2. Contact with the usual kinetic theory by appropriate
   integration of the equations and introduction of the Mayer-
   Bogoliubov cluster expansion; and

   3. Recognition that the space-velocity operator governing
   the generalized correlations is anti-Hermitian and that
   therefore in the N-momenta description the plasma oscilla-
   tions are bounded. (See also, previous progress report,
   June 1, 1964.)

The preliminary results (1) and (2) and (3) indicate that microin-
stabilities indeed are self-limiting in spatially-homogeneous plasmas
without magnetic field. However, much more detailed understanding
of the process by which this occurs is required. Moreover, the
self-limiting of coherent fluctuations ("macroscopic" variations
in space) and the effects of magnetic fields are of major importance.

The N-momentum description has now been extended in two essential ways.

   1. Magnetic Field. The master equation for a spatially-
   homogeneous plasma imbedded in a uniform magnetic field has
   been derived. The work is still in progress; however, it
   appears that the major results of the theory for zero magnetic
   field go through without essential change. Extension to
   fluctuating fields and spatial variations is being studied.

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* The generalized correlations are the analog in N-momentum space
of two-body correlation functions. They are functions of N momenta
and two spatial coordinates.

2. <u>Coherent Fluctuations</u>. The N-momentum description has now been extended to include the case of moderately strong coherent spatial fluctuations with no magnetic field. The results lead to a coupled set of three <u>linear</u> equations analogous to the Vlasov-Balescu-Lenard set <u>of the</u> usual kinetic theory. (The major task has been to achieve a physically reasonable <u>closure</u> of the general hierarchy of N equations.)

Our success in this regard was reported[2] at a recent meeting of the American Physical Society.

The closed set of three equations are now being studied as our main tool in describing the development and self-limiting of microinstabilities in plasmas. The space-velocity operators are all anti-Hermitian as expected, and precisely of the form discovered in Reference 1. Search is underway for the eigenfunctions of these basic operators.

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A RESEARCH PROGRAM IN SPACE ELECTRONICS

Investigator: J. F. Reintjes
Project No.: DSR 9948

This NASA grant includes two tasks. Task 1 is an investigation of conduction processes in thin films, and Task 2 is research on computer-aided design of space electronic circuits. The work performed on both tasks from June 1, 1964 through November 30, 1964 will be reported upon in detail separately by the Electronic Systems Laboratory.

In brief, work under Task 1 involved: measurements of trap density of thin CdS films in order to determine the number of traps per unit volume and their energy distribution; a study of surface phenomena of thin CdS films; a study of gold-film structure when deposited on a CdS film surface; thermally stimulated emission currents in CdS films; a study of negative resistance effects in CdS diodes. All of these investigations are being undertaken in an effort to gain an understanding of the fundamentals of conduction processes in thin films of semiconductor materials.

Under Task 2, investigations are being conducted through use of MIT's Project MAC Computer on computer-aided synthesis and analysis of nonlinear active and passive networks subject to certain constraints; synthesis of logical networks, given the overall input-output specifications for the network and the set of basic logic blocks to be used; investigations leading to the simulation of active and passive networks by digital-computer means. The ultimate goal of this research is to develop effective procedures for using digital computers as a powerful design tool for electrical circuits with emphasis on circuitry for space applications.

MINIMUM FUEL SYSTEMS

Investigators: M. Athans, D. L. Kleinman
Project No.:   DSR 9952

Introduction

The object of this research is to consider the theoretical and practical aspects of fuel-optimal controls systems using the Maximum Principle of Pontryagin. In all of the problems, the consumed fuel required to accomplish a required control task is included in the performance criterion. In addition, other quantities of interest (e.g., the response time) are also included in the performance criterion.

This research project is at present at its preliminary stage. Currently, the investigations are focussed on the following two problems:

1. Investigation of Satellite Attitude Controls from the Point of View of Minimizing a Linear Combination of the Consumed Fuel and of the Response Time

This problem represents the natural extension of previous investigations[1,2] to the design of a nonlinear time-invariant satellite attitude control system. The basic optimal design is modified so that the limit cycle (which will arise from imperfections in the gas jets) will not consume a large amount of fuel. A report on this project is under preparation.

2. The Theory of Fuel-Optimal Systems

This study is concerned with the questions of existence, uniqueness, and possibility of singular solutions for the general minimum fuel problem, under the assumption that the controlled plant is linear, time-invariant, and of arbitrary dimension. Certain preliminary results concerning the existence of solutions and the possibility of optimal controls have been obtained.

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ROLE OF COST FUNCTION IN ENGINEERING OPTIMIZATION

Investigators: R. L. Halfman, G. Steinker
Project No.:   DSR 9953

The purpose of this research is to investigate the nature of the performance criteria and its effect upon the optimal solutions to problems in engineering optimization. During the initial months a literature survey has been conducted with special emphasis upon the form of cost functions employed in the optimization of engineering systems. The majority of previous work has been carried out for:

1. Automatic feedback control systems or regulator systems (predominantly linear) in which it is desired that the output of a dynamic device follow a command input and remain stable under uncontrollable noise inputs. For these systems the performance criteria chosen are the integral square error or mean square error.

2. Terminal control systems, predominantly employed in aerospace systems for the optimization of flight trajectories, in which it is desired to reach, from given initial conditions, a desired terminal state. The performance criteria are usually formulated in terms of the terminal values of the state variables.

Very few partially observable or stochastic terminal control systems have been examined. It is felt that, with the addition of accuracy requirements into the performance criteria for these systems, the optimal solutions could be significantly altered.

Future research will be conducted towards the construction of a generalized dynamic terminal control system with a time-dependent cost function. A re-entry guidance system may well serve as a useful trial application.

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LABORATORY FOR SPACE EXPERIMENTS

Investigators: R. H. Baker, H. S. Bridge, R. J. Butler,
                J. V. Harrington, W. L. Kraushaar, R. W. Rasche
Project No.:   DSR 9947

The Laboratory for Space Experiments commenced operations on a
very modest scale during the current reporting period.

A substantial amount of effort in the first quarter was devoted
to organizing the activity, equipping suitable laboratory facilities,
and hiring professional and technical personnel.

Three programs are presently underway within the Laboratory; these
are: the MIT Gamma Ray Telescope, the A-IMP Plasma Probe, and the
Sunblazer program.

MIT Gamma Ray Telescope

This program invisions a number of measurements of the gamma ray
intensity of the universe. Of especial significance is an inves-
tigation of the unique way in which gamma rays are produced and
whether they are of galactic or extragalactic origin.

The measurement instrument consists primarily of a central counter
and a Cerenkov counter which make up a "telescope" in the sense
that when a charged particle traverses the instrument from the
forward direction, the two counters respond simultaneously. If
the cause was an incident-charged particle, the veto counter also
responds and wipes out the record of the simultaneous event. But
if the incident particle was a gamma ray, the veto counter does
not respond, and a signal is telemetered to earth giving an indica-
tion of the energy lost by the electron-positron pair that activated
the central scintillator.

The new electronics associated with this OAO-A experiment are being
designed and assembled for the Laboratory of Nuclear Science.
These electronics provide on-board signal processing capability
for the measurement electronics which were designed for interface
with the Explorer XI vehicle. The new electronics also provide
the necessary data-control functions and interface between the
measurement electronics and the central processing unit of the
OAO-A vehicle.

A-IMP Plasma Probe

In September the Center undertook a joint experiment with the Laboratory for Nuclear Science. The plasma probe consisting of a Faraday cup and electronics package to be placed in a lunar orbit is designed to measure the proton and electron fluxes in the energy regions from a few ev to about 3,000 ev.

The electronics are being designed and built by the Laboratory for Space Experiments and consist primarily of four sections: the measurement chain or signal conditioner; the modulator, which controls voltage on the Faraday cup; the logic system which performs signal processing, on-board storage and data control; and the interface function with the A-IMP spacecraft; and the low-voltage power supply.

The electronics system design has been determined and work on a breadboard is underway.

Sunblazer

This program contemplates the placement of a small satellite in orbit about the sun to observe the effect of the interplanetary medium on signals transmitted from the satellite to the earth as the satellite recedes from the earth and is eventually occulted by the sun.

Considerable initial effort has been devoted to the design of the spacecraft. Stabilization of the spacecraft along a solar radius through the action of radiation pressure is being studied. Various vane designs and libration damping mechanisms are being considered.

Possible Sunblazer orbits are being studied as are modulation techniques to take advantage of the higher average powers attainable from the oriented solar panels.

SOCIAL SCIENCES

THE IMPACT OF R AND D ON THE U. S. ECONOMY

Investigator: W. H. Gruber
Project No.:   DSR 9830

Research effort of this project has been divided into the following three stages:

> 1. To determine the ways in which the economy has functioned differently in the postwar period, when the expenditures on R and D were large, relative to 1909-1929, the first normal period before R and D expenditures were significant.
>
> 2. To attempt to evaluate the specific effects that R and D has had on the functioning of the postwar economy utilizing the findings in stage (1) for perspective.
>
> 3. To utilize the understanding of the impact of R and D derived from stages (1) and (2) in order to consider the future role of R and D and the ways in which better understanding can maximize the usefulness of R and D while minimizing the disruptions in the economy caused by it.

The first stage has been largely finished and a complete report of this research is available in the two MIT School of Industrial Management working papers listed in the Second Semiannual Progress Report.

Work on the second stage has been concentrated on the impact of R and D on the functioning of labor markets and the role of education in the technologically more complex society of the postwar period. The sectoral impact of productivity increase, where those sectors with the fastest increases in productivity have had the smaller increases in employment, is one finding of this research. The occupational impact has been analyzed, and it was found that occupations that have had the highest educational attainments are those occupations that have increased in employment the most rapidly.

The role of education in the more technologically complex economy has been analyzed from two different perspectives. The work described above is part of a project that is almost in finished manuscript form under the title "Productivity, Education and Changes in the Labor Force." The second facet of the overall project related to education is designed to measure the changes that have taken place during the postwar period in the education of scientists and engineers. The theme of this research is based on the proposition that there are four discernible stages in the evolution of scientific manpower in the United States. The first of these

stages, far removed from today's world, consisted of a free market in which random events dominated and scientific progress was a function of the discoveries of independent inventors and entre- preneurs[5,6,8]. The waning years of this stage witnessed the emergence of a new aspect of scientific activity--organized team action in research and development. World War II, with its powerful demands on technology, brought about the second stage, in which the federal government became deeply involved in the progress of science. Science thus became an instrument of national policy, but national goals were related to crises, and the need for long-range planning was not felt[15]. During the postwar years, the growth of atomic energy with a number of revolutionary defense systems, the arrival on the scene of Sputnik and the rapid sequence of events that followed (National Defense Education Act, National Aeronautics and Space Administration) all set the stage for long-range effects without a full understanding of what these effects might be.

Stage two continued until the early 1960's, when it began to phase into stage three. By the time of transition between these two stages, federal involvement in science was such that two-thirds of all money spent on research and development came from federal sources[11].

During the late 1950's and increasingly in the 1960's, the impact of federal actions on the health and functioning of the scientific community has been questioned. It is therefore difficult to date precisely the beginning of stage three. Due to the greater intensity that has characterized the questioning process in the early 1960's, it is this period that has been selected as the beginning of stage three. The key change in the parameters has been the prospective slackening in the rate of increase of government-sponsored R and D. This has forced upon the government officials and practitioners of R and D the problem of resource allocation. In turn, this has brought into focus the problems of efficiency and the question of national goals.

Questioning the current health of the scientific community has taken many forms. It has been claimed that government-sponsored R and D is consuming the nation's "seed corn" as educators are bid away from their classrooms[10]. It has also been observed that there has been so much technological progress that obsolescence of scientific knowledge now represents a formidable problem[3]. It has been claimed that there will soon be a great shortage[14], but it has also been alleged that there will be a surfeit of trained scientists and engineers[2]. It has been found that National Merit Semifinalists, considered to be the most highly qualified secondary school graduates, are expressing less interest in science and engineering[12]. The quality of input into schools of science and engineering has improved considerably, however[13].

Stage three, consequently, has been a period of uncertainty, questioning, and slackening of the heretofore very rapid pace of growth. The levelling off of its growth is a necessary consequence of the 19.8 percent per year rate of increase between fiscal years 1940 and 1965 in the federal budget for R and D activities and facilities, for if this trend is projected to 1980 one must conclude that by that time all government expenditures would be made for R and D[4]. The necessity for long-range planning has been recognized by both the government and the scientific community[7]. It is recognized that substantial changes in the functioning of the scientific community have resulted from government policies and the rapid evolution of technology. A high level of scientific strength has been developed and the problem now is not crisis response but efficient management of a great national resource.

Stage four is approaching, and it should bring with it a high degree of national planning characterized by an integrated national manpower policy. There are, of course, limitations to the scope of such a policy. "This is not to suggest that the United States must develop a conscious 'master strategy' for manpower development and utilization...the main objective of any 'national manpower policy' is not to regulate but rather energize the activities of thousands of decision-making organizations by providing them with information, tools, and ideas for better assessment of the total impact of their decisions."[9] Nevertheless, the existence of the policy must rapidly become fact. That effective education, in particular higher technical education, is an integral part of such a policy, is obvious. The source of trained top-level technical manpower is the educational system, and the quality and quantity of its output are basic factors in management of the manpower resource.

The plan is to utilize the experience at MIT to gain further understanding of the postwar changes in scientific education that are leading to evolutionary stage four. The model of change in MIT's educational plans has been divided into three phases: input, processing, and output. This work will integrate with the findings in "Productivity, Education and Changes in the Labor Force"[1] and will therefore provide, in sum, an analysis of the total spectrum of education.

In addition to the changing role of education in the more technologically complex world created by R and D, research in stage (2) on the impact of R and D has been conducted in the following four areas: (a) economic growth and productivity; (b) management activity and competitive practices; (c) manpower requirements; (d) societal changes. An example may help to illustrate the direction in which the other facets of stage (2) are being investigated. Increases in man-hour productivity result from a number of forces such as economies of scale, competitive pressures, and education of the labor force. More efficient processes which result from R and D compose, therefore, merely one of the variables which help to create productivity improvements. A proposition of this research project is that it is

incorrect to consider technological innovations as the only impact of R and D. In the case of nuclear-power generating equipment, for example, the contribution of nuclear power would not merely be considered by itself in the research design of this project. Nuclear power has created a competitive battle with coal that is leading toward greater efficiency in the mining and transportation of coal. Although nuclear energy is technologically complex, it has led to such conceptually simple innovations as the unitized train for the hauling of coal. Extra high-voltage transmission of electrical power is an innovation coming from R and D which has made possible the location of power electrical-generating stations right at coal mines. It has also led to the advantages of economies of scale, as larger generating stations can now economically transport power to the final consumer through EHV lines.

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PUBLIC POLICY ASPECTS OF SPACE RESEARCH

Investigators: R. C. Wood, E. Skolnikoff, E. Bok, M. Mobius,
D. Lerner
Project No.: DSR 9831

International Aspects of Space Research and Development

Further revision and refinement have been underway on the draft
manuscript, which focuses on: (1) the scientific and technological
aspects of policy-making in foreign affairs, and (2) the oppor-
tunities offered by science and technology for creative policy
initiatives. The expected date of completion is March 31, 1965.
In addition, a paper entitled "The Scientific and Technological
Component in Policy-Making for Foreign Affairs," drawn largely
from the material of this study, will be delivered at the annual
meeting of the American Association for the Advancement of Science
in Montreal on December 26, 1964.

The Research Process

In the last six months, a general study of sponsored research
activities at MIT has been carried to the analysis stage. Total
magnitudes of research efforts within the various departments have
been established and related through indices to educational charac-
teristic and variations in the allocation of time by staff members.
Formal and informal processes of origination and authorization of
large research projects have been identified. An extensive inter-
view project within the Physics Department has been completed,
results coded, and final write-up underway.

Taken together, these investigations are throwing considerable
light on the impact of large mission-oriented support on research
choices made by individuals and groups working in an academic
context. They also have proved useful in identifying systematically
different types of academic researchers and the relation between
the character of research and discipline involved and awareness
of public policy implications. A monograph reporting initial
findings is expected to be completed by February 1965.

Public Support for the Space Program

This research, with emphasis on participation of elite groups and
influentials, is being actively carried forward. Expected date of
completion is February 1965.

The Telestar Legislation

This research on the communication network in the policy process that led to the Communication Satellite legislation has been completed. Copies of the dissertation are available.

European Scientists

A study is underway at CERN exploring different professional behavior patterns and social backgrounds among different nationality groups represented among scientists there. The objectives of this study are to account for observed variations in performance and to explore the effects of international collaboration on the political and social outlook of individual scientists. Findings are to be compared with similar studies now going on at EURATOM, a panel of distinguished European scientists, and the research process project at MIT. We expect, therefore, to provide a reliable comparative analysis of scientific work and to be able to establish empirically the degree to which international scientific ventures contributed to the emergence of common views and attitudes.

LIFE SCIENCES

RESEARCH IN PSYCHOBIOLOGY

Investigators: H. L. Teuber, R. Held
Project No.:   DSR 9828

During the period under review, the research efforts of the MIT
Psychological Laboratories have continued to concern three areas,
viz., (1) brain and behavior; (2) perception and learning; and
(3) social-developmental psychology (including psycholinguistics).
Accordingly, progress will be described, in turn, under each of
these three headings, although overlap among the sectors will be
apparent.

The review will have to be selective; it is not intended to take
the place of individual publications which issue from this program;
these publications are listed at the end.

1.   Brain and Behavior (Physiological Psychology)

As in the past, work in this area proceeds by way of studying the
aftereffects of early or late brain injury in man, and by experi-
mental analysis, in lower forms, of behavioral effects of cerebral
ablation or stimulation. These studies are increasingly supple-
mented by electrical recording, e.g., computer averaging of brain
potentials evoked by light in man, and by recording with macro- and
microelectrodes from the animal nervous system during perception
and learning. Similarly, work proceeds on chemical changes, observed
on microscopic levels (by radioneurography) in the brain, during
various functional states, such as the rearing of animals in enriched
environments, or under conditions of special visual or auditory
stimulation or of enforced exercise. Finally, with the arrival of
Professor Walle Nauta, neuroanatomical studies are beginning with
particular reference to the limbic system in the brain, the motor
systems, and some of the potential pathways for pain.

A further event of note was the opening, during the period under
review, of the Clinical Research Center at MIT, jointly operated by
representatives of the MIT Medical Department and the Departments
of Nutrition, Electrical Engineering, and Psychology. This new
facility has permitted us recently to extend our tests of brain-
injured veterans and brain-damaged children to prolonged periods
of observation in a controlled environment where these patients can
be hospitalized for several days or weeks.

Among the recent findings resulting from these neuropsychologic
studies are further data on behavioral effects of frontal-lobe
injuries in previously healthy adults and new evidence for ipsilat-
eral motor symptoms after unilateral brain lesions, in analogy to

earlier findings from these laboratories of correspondingly ipsilateral sensory deficits. Work with brain-injured children tends to support the view that early injuries produce behavioral consequences that are less focal than injuries sustained later in life, yet the specialization of the two hemispheres--the left for linguistic, the right for certain perceptual-motor skills--may well be present before the acquisition of language, since lateralized injury of the brain in the new born already has differential effects depending on the side of the brain that is affected.

Results of ablation studies in subhuman forms have further defined, for the rat, those effects of large cortical destruction which were previously considered as due to interference with some hypothetical mass action. As it now turns out, anterior cortical lesions impair alternation, while posterior cortical lesions impair spatial orientation; lesions large enough to involve both areas produce combined effects which resemble mass action but are actually dissociable into the two component symptoms just described. Furthermore, mediodorsal thalamic lesions in the rat, as well as caudate lesions, impair alternation in a manner essentially comparable to removal of frontal cortex.

In a more recent extension of these experiments, performance on tasks involving active and passive avoidance was contrasted for rats with different cortical and subcortical lesions; active avoidance was found to be impaired after caudate, or ventral hippocampal lesions; passive avoidance after dorsal hippocampal destruction.

Work on electrical stimulation of the animal brain has led to further confirmation of two opposite effects, viz., impairment of learning as well as facilitation. Impairment is being obtained on stimulation of intralaminar thalamic nuclei (cats, rats), soon (1-2 seconds) after a visual choice; by contrast, stimulation through the same electrode during a choice apparently facilitates learning of the visual discrimination. Facilitation of learning has also been obtained quite recently with biphasic (300 cps) current stimulation of posterior cortex, a maneuver which improved retention in rats after single runs in an open-field maze. On the other hand, repeated efforts at producing amnesia for one trial in a maze, by a single electrically-induced convulsion (ECS), in the rat have been unsuccessful, indicating that earlier results from these laboratories were correct, viz., that interference with retention of single-trial learning by ECS can take place only if the treatment (ECS) follows the trial either immediately, or at least within less than 10 seconds.

Altogether, these recent experiments suggest that memory consolidation is a brief affair, requiring a few seconds or less, for simple tasks, and that the nonspecific thalamus and caudate nucleus may play important roles in the fixation of the memory trace.

Current experiments involving electrical recording during percep-
tion and learning are not far enough advanced to permit conclusions,
but the laboratories have obtained definite evidence during the last
six months that units in the monkey's inferotemporal cortex are
responsive to light; these neurons are in the region where destruc-
tion (or reversible ablation by electrical stimulation) leads to
drastic deficit in visual discrimination learning. In contrast
to these findings based on macroelectrodes, computer averaging of
photically evoked potentials, in the monkey, have not yet been shown
to be affected by inferotemporal ablation; however, resection of
one occipital lobe leads to alterations in visual evoked response,
not only on the operated but also on the intact side.

Last, but not least, the period under review has seen considerable
extensions of neurochemical analysis, especially neuroradiography.
Injections of tritiated leucine and of tritiated thymidine have
shown, respectively, that rearing of rats in an "enriched" environ-
ment leads to marked increases in the formation of cortical glia,
and concurrently, to decreases in protein formation. Further uses
of thymidine-H^3 have again revealed that in the rat, not only do
glia form postnatally but that granule cells in the hippocampus
and elsewhere incorporate thymidine after birth. Radioactive
labelling of sex hormones has led to the conclusion that the hippo-
campus, in addition to the hypothalamus, may be an area of the rat
brain in which radio-labelled estradiol is taken up. All of these
studies, and related experiments in psychobiology, are being actively
pursued.

2. Perception and Learning

In the area of general experimental psychology, the laboratories
have continued to be concerned with further studies of rearrangement
and disarrangement in relations between stimulus input and perceiver;
with problems of temporal factors in visual functions; with color
and brightness perception, and with questions of short-term memory
as compared with long-term effects.

During the last six months, work continued on the basis of sensori-
motor coordination, with special emphasis on problems of adaptation
to prism-induced displacements or distortions of visual input. The
principal experiments included: An attempt at deciding whether
adaptation to visual displacement (by prism-bearing goggles) can
be reduced to a mere shift in the position of one's limbs. Reaching
for visually-presented targets has been shown to improve rapidly,
if the person bearing the goggles was permitted to view his hand
through the goggles, while engaged in active (self-produced) move-
ments. Recent experiments from these laboratories show that this
successful adaptation is specific to visually-guided reaching. If
the person is required, instead, to point at the subjective straight-
ahead position without any visual target, no shift in direction of
pointing is obtained.

In other experiments in this series, the human sensorimotor loop
is being influenced by introducing various amounts of external
force against which the perceiver has to move his limbs during
active localizing movements. As a result, conditions which produce
varying amounts of decay in coordination can be specified; variable
external forces tend to produce the most conspicuous deterioration
in performance.

In a third class of experiments on rearrangement, efforts are made
to define the level in the nervous system at which adaptation to
disturbing media takes place. Vertical stripes moving along the
horizontal meridian of an observer's field induce optokinetic
nystagmus in the horizontal plane. Following adaptation to goggles
which initially induce a tilt of all perceived verticals, vertical
lines are again perceived as upright as long as the goggles are
worn, and as tilted (in the opposite direction) immediately after
the goggles are removed. A system consisting of rotatable photo-
electric cells has been constructed to monitor the plane of opto-
kinetic nystagmus. With this arrangement, it has been demonstrated
that perceptual adaptation to induced tilt of lines is not accom-
panied by corresponding shifts in the plane of optokinetic nystagmus.

Taken together, these experiments on perceptual adaptation begin
to delineate the limiting conditions for sensorimotor adjustment
to extreme environments, including the questions of responses to
varying or absent gravity.

In other experiments on perception and learning, intensive studies
are being made of phenomena involving short-term interaction between
successive visual stimuli (e.g., masking and metacontrast), under
conditions of successive stimulation of one eye, with varying inter-
polated intervals, or of both eyes, with one eye receiving the
first and the other the later stimulus. In addition, there is
continuing work on brightness enhancement and color-effects for
brief or repeated flashes of monochromatic lights, and systematic
exploration of the color-space of normal human observers. This
last experiment involves extensive computer analysis.

Emerging from all this work are some generalizations about temporal
factors in form perception, and, hopefully, some decision about the
relative adequacy of a three-receptor theory of color vision, as
against those theories which invoke opponent processes.

Finally, there is considerable experimentation involving verbal
learning, with particular reference to phenomena of short-term
memory for numbers, letters, syllables, and tones. A general con-
clusion emerging from these studies is that short-term memory in
man can best be described by a simple associative theory and that
the laws governing long-term memory can be found replicated, one
for one, among the phenomena of short-term recall.

3. Social-Developmental Psychology (including Comparative and Psycholinguistic Studies)

In this third area of major endeavor, work continues to be concentrated on a series of selected but related issues in comparative, development, and social psychology. In comparative studies, stress is laid on the emergence of certain behavioral mechanisms at different phylogenetic levels. Thus, experimentation on problem-solving by tree shrews (Tupaia) continues, with special reference to similarities and differences between this unusual form (transitional between insectivore and primitive monkey) and ordinary primates. The Tupaia in the departmental colony have now been shown to master delayed response, with delays up to 8 seconds, but their performance is surprisingly unstable. Following bilateral prefrontal resection (in one animal), delayed response performance was lost, as it is in real primates.

Extensive studies proceed on goldfish, with particular emphasis on their capacity for active avoidance learning, and on visual memory for patterns presented to one eye and tested in the other (untrained) eye at varying periods afterwards. There is the promise of more general rules, determining when information can be transferred from eye to eye via the tectal commissural pathways and when it cannot be transferred. These continuing studies are supplemented by observations on the surprising limitations of intraretinal transfer of visual information in this species, and by more recent experiments on effects of commissural section on transfer, and on effects of cooling of one or the other optic lobe on retention and recall.

Other comparative psychological experiments deal with "curiosity" in hamsters: These rodents show alley running for the sole "reward" of experiencing a novel object; more recent observations suggest that familiarity with objects (loss of the "novelty" effect) might be demonstrable after intervals of several months.

Work on problems of early development has dealt with the origin and maintenance of visual perception and visuomotor coordination in very young kittens; in man, developmental studies have been concerned with infants reared under conditions amounting to severe deprivation (in an orphanage), and under varying conditions of environmental enrichment.

The work on newborn kittens continues to inquire into the possibility that the perceptual deficit of animals reared under sensory deprivation (e.g., without "patterned" visual stimulation) may be understood in terms of the same factors which were found to be crucial in adaptation of human adults to prism-induced rearrangement of visual input. Adaptation to such prisms, in man, had been shown to be promoted by active movement of the perceiver, in a visually patterned environment. Passive motion of contours across the eyes had little or no effect.

Analogous experiments with very young kittens demonstrated that exposure to visual patterns was a prerequisite of normal perceptual development; purely passive transportation of the kittens in a patterned surrounding resulted in animals who failed to exhibit visually guided contact-placing, had no blink reflex to approaching objects, and performed randomly in response to apparent depth on a "visual cliff."

During the period here reviewed, experiments were undertaken to further define these deprivation effects. Does purely passive exposure constitute a positive hindrance of normal perceptual development? Or does passive motion, on the contrary, provide some limited but useful perceptual experience which could be manifested in the form of savings scores on subsequent training?

Results showed that passive experience preceding active motion will neither accelerate nor retard the subsequent acquisition of the three visual-spatial skills, viz., paw placing, blink responses, and reactions to the visual cliff. When kittens were reared in holders permitting active head movements, but not locomotion involving their whole body, they were found to show normal paw placing and normal blink responses under visual control, but acted randomly on the visual cliff, as though their sensorimotor development was specifically limited by the experiences provided during rearing.

In recent work with human infants, a similarly crucial and specific role of early experience is being observed: Sensorimotor development has been charted from birth in orphanage-reared children, who grow up with minimal handling and in uniform visual surroundings. These infants are greatly retarded in visuomotor skills and other aspects of coordination. However, their development can be normalized or even accelerated by graded enrichment of conditions of rearing such as minimal additional handling of the infant during the first two months of life, or the providing of mobile toys placed overhead, or on the sides of the crib.

Additional normative studies deal with the emergence of the grasp reflex of hand and foot in normal infants, and with the development of accommodation, convergence, and blink reflexes during the first few months of life. Speech development in environmentally deprived and retarded children, with early brain damage, is being observed during prolonged periods of care at the MIT Clinical Research Center where several previously speechless children of this type are now found to speak after relatively short periods (1-3 weeks) of hospitalization in this special environment.

Other current psycholinguistic experiments in normals continue to exploit the phenomenon of subjective displacement of clicks heard through one ear, while a sentence is presented to the other ear. We now have definite proof that this displacement of the click (towards the nearest syntactic junction point) does depend on syntactic structure and that the striking differences between right and left

ears of normal listeners (effects described in previous reports) are abolished when a sentence is decomposed into a random list of component words. The technique lends itself to the study of language learning in young children and to analysis of their grasp of syntactic structures.

Lastly, work continues intensively on the problem of acquisition of values by children and on the role of peers as sources of social influence. Intriguing age differences emerge showing that effects of social influence tend to carry over more markedly from one test situation to another in older children than in younger children, and that fairly consistent differences appear in this respect between boys and girls when age is controlled.

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Wickelgren, W. A.: Phonemic Similarity and Interference in Short-term Memory for Single Letters. J. Exp. Psychol., in press.

INFORMATION TRANSFER IN PREBIOLOGICAL ENVIRONMENTS

Investigators: A. Rich, G. Giannoni
Project No.:   DSR 9832

Among the most important chemical reactions necessary for the emergence of life on this planet were the development of polymer molecules which were capable of interacting with other species of polymer molecules in such a way that their sequence of monomer residues was specific. Chemical systems of this type have given rise to the polynucleotide molecules which are responsible for carrying genetic information and which have built into their molecular structure the complementarity necessary for macromolecular replication. As part of our general project of exploring information-transferring mechanisms, we are interested in exploring ways in which the information transfer may be carried out in environments which differ from that which is currently found in biological systems. Some of these environments may be closer to that which existed in the varied chemical environments which occurred in the early history of this planet.

In this particular study, polynucleotide molecules were used which are similar but not identical to those found carrying genetic information in contemporary biological systems. Some time ago, we were able to show that polyinosinic acid and polycytidylic acid both combine together to form a 1:1 helical complex in which the purine and pyrimidine bases are hydrogen bonded together in a specific manner. The form of this hydrogen bonding at neutral pH is identical to that which is seen in the hydrogen bonding between purine and pyrimidine residues in DNA, the major carrier of genetic information. In this investigation, we studied the effect of an alteration in the hydrogen ion concentration on the stability of this molecule. When the pH of the solution is lowered, this double-stranded helical molecule breaks up and the two strands are separated from each other. Thus, at a pH of approximately 5, the polynucleotide helices are no longer hydrogen bonding with each other in a specific manner and accordingly, these molecules could not serve as a basis for information transfer and molecular replication. However, on raising the proton concentration to pH 4, it was found that a new polynucleotide helix formed involving protonated polycytidylic acid combined with polyinosinic acid. In this newer polynucleotide helix, the purine and pyrimidine residues are hydrogen bonded to each other in a specific manner but they no longer form the same structure which is found in the naturally occurring DNA molecule.

The significance of this observation is that it is possible for polynucleotide molecules to form complementary helical complexes with each other under a variety of conditions, not only those which

are found in contemporary bilogical organisms but also under conditions which are far removed from them chemically.

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SELECTION OF MICROBIAL MUTANTS IN CLOSED SYSTEMS

Investigators: R. I. Mateles, T. Yasuda, R. Silver, D. Y. Ryu,
                      D. P. Mukherjee
Project No.   DSR 9833

Growth on Multiple Limiting Substrates

As reported previously, with <u>Pseudomonas fluorescens</u> complete
utilization of glucose and fructose when fed simultaneously into
a continuous culture can be achieved provided the growth rate is
below about 0.27 hr^{-1}. Above this growth rate, the fructose is
not utilized. With <u>Escherichia coli</u>, qualitatively similar results
were obtained, the breakpoint occurring at 0.60 hr^{-1}. With the yeast
<u>Saccharomyces cerevisiae</u>, however, a different pattern was observed.
Even at very low growth rates, below 0.1 hr^{-1}, there was a signi-
ficant amount of unconsumed fructose. The glucose concentration
rose rapidly as the growth rate increased, and the fructose con-
centration was always considerably higher than that of the glucose.

The work is being continued in an effort to determine the extent
to which catabolite repression and inhibition or competition are
responsible for the phenomena observed.

Tryptophan Pathway Mutants

The attempt to secure a mutant derepressed in the enzymes between
anthranilic acid and tryptophan by continuous culture on limiting
anthranilic acid failed because the parent organism, an anthranilic
acid-requiring mutant reverted sufficiently frequently so that
prototrophs accumulated, rather than than the desired derepressed
organisms. The experiments have been discontinued.

Dynamic Response of Continuous Culture

These experiments, designed to characterize the dynamic response of
a steady state continuous culture, continue. <u>Escherichia coli</u> is
the organism used, and the disturbance introduced has been an increase
in dilution rate resulting in a response of increasing growth rate.
The time course of this response has been obtained by numerical
differentiation of a record of concentration of limiting nutrient
versus time. The results indicate that the cells increase their
growth rate immediately by about 0.2 hr^{-1}, which is followed by a
slow increase with a time constant of the order of 60 minutes.
Thus, if the disturbance is small (a dilution rate change of less

than 0.2 hr^{-1}) the culture immediately adjusts to the new steady state, while if it is larger a lag followed by an overshoot in growth rate results.

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EFFECTS OF REPEATED ISOMETRIC MUSCULAR EXERCISE AS A MEANS

OF PRESERVING MUSCLE MASS DURING PROLONGED CONFINEMENT,

ON PROTEIN AND AMINO ACID REQUIREMENTS

Investigator: J. B. Das
Project No.:   DSR 9834

During the past summer, a 66-day related study was sponsored by
the U. S. Army Medical Research and Development Command. The
diets supplied either (1) 35 calories/kg body weight/day or (2)
50 calories/kg body weight/day, and contained 0.8 gm protein/kg
body weight/day, with two hours daily of strenuous physical work
on a treadmill for 44 days. The 50-calories group showed a small
transient loss during the work phase only, and the net weight
change was positive. The 35-calories group lost weight throughout.
Nitrogen balance changes are still being analyzed.

On the basis of this experience, the title and plan of the present
study has been changed. The immediate objective is to quantify
the effectiveness of static work in the maintenance of muscle mass
and strength, while consuming an adequate liquid diet during pro-
longed periods simulating restriction in a space vehicle; and the
long-term objective is to determine the effect of such exercise
on protein needs and the proportion of essential amino acids
required.

Since the study entails considerable restriction of the activities
of the subjects, it had to be deferred until the opening of the
Clinical Research Center. Highly motivated Mennonite volunteers
have been promised, and the project will begin in early 1965.

An amino acid autoanalyzer and a heavy-water apparatus for total
body water studies have been purchased and are being standardized.

ENZYMATIC SYSTEMS INVOLVED IN NITROGEN FIXATION BY MICROORGANISMS

Investigators: J. M. Buchanan, R. Lattrell, K. Taylor
Project No.:   DSR 9949

As indicated in the original proposal, work in this project involves the microorganism <u>Clostridium pasteuerianum</u>. Extracts of this organism had been separated into two parts, whose recombination was necessary for nitrogen fixation. A heat-stable fraction catabolizes pyruvate, the electron donor, and forms an intermediate compound or compounds, which support nitrogen fixation when added to the second fraction. The second fraction is a supernatant after adsorbtion with calcium phosphate and presumably contains the enzyme attacking molecular nitrogen, nitrogenase. It is our intention to isolate and identify the necessary components of each of these fractions.

Since the activity of the heat-stable fraction is very labile to air, it has been necessary to develop techniques for its anaerobic handling and analysis. Among those developed have been anaerobic transfer, centrifugation and column chromatography. Using these techniques it has been possible to separate components of high molecular weight, presumably enzymes, from those of low molecular weight, cofactors.

Two cofactors have been identified and commercial preparations have been substituted for those isolated from the heat-stable fraction. Coenzyme A is necessary for the catabolism of pyruvate in the presence of the enzymes. There is evidence that flavine adenine dinucleotide is necessary for nitrogen fixation in the presence of the enzymes of the heat-stable fraction and nitrogenase. Recent evidence indicates that other cofactors are also necessary for nitrogen fixation. The attempt to identify these is going on presently.

Concurrently the purification of nitrogenase has been attempted as a prerequisite to studies on the mechanism of reaction of the nitrogen molecule. Since the activity of nitrogenase slowly decreases upon exposure to air, the anaerobic techniques mentioned previously are used for its handling and purification.

It has been established that the activity is associated with a large molecular weight fraction, which is probably protein. The time course of the reaction and the response to concentration of enzyme are identical to those expected for enzymatic reactions in general.

Attempts by some of the usual techniques of enzyme purification have resulted in considerable loss of activity. Attempts at precipitation by ionic strength and by organic solvents were made with discouraging

results.   However, some purification has been achieved by column chromatography on calcium phosphate.   Additional purification methods are currently being tried.

DEVELOPMENT OF A SYNTHETIC DIET FOR

NUTRITION AND METABOLISM EXPERIMENTS

Investigators: A. E. Harper, S. A. Miller
Project No.:   DSR 9950

The composition of the diets used in studies of nutritional requirements and of factors influencing metabolic processes must be known with great accuracy. Highly purified diets have been developed for such studies, but even these contain naturally occurring proteins and carbohydrates and usually commercial fats. These materials, which represent the major components of highly purified diets, contain impurities, some of which can influence the response of an experimental subject or the analytical results obtained in an experiment. The objective of this project is to determine the feasibility of substituting synthetic components for purified natural materials.

In previous work on this problem, mixtures of crystalline amino acids have been substituted for dietary proteins and a combination of amino acids has been devised that will support high-quality proteins. Synthetic materials capable of serving as dietary energy sources have also been studied. Two synthetic products have been synthesized which can serve as energy sources for experimental animals without causing deleterious effects. These compounds can be substituted for carbohydrate in high-fat diets, thus making possible the preparation of diets of high caloric density containing no crude carbohydrate. The substitution of amino acid mixtures for protein, of synthetic products for carbohydrate, and the availability of synthetic fats now brings within reach the possibility of developing a diet consisting wholly of synthetic components.

We plan to extend our current studies of amino acid mixtures and synthetic sources of dietary energy in an effort to develop a diet that approaches closer to being completely synthetic than any so far devised. If this proves successful in growth and performance studies with small experimental animals, the project may be expanded to include human metabolism studies.

Completely synthetic diets are unlikely to provide the solution for practical feeding problems; nevertheless, they will be valuable in experimental studies of the effects of environmental changes on nutrient needs and on metabolic processes.

PRODUCTION OF EDIBLE PROTEIN OF MICROBIAL ORIGIN

Investigators: S. Tannenbaum, R. Mateles

Project No.:   DSR 9951

This research project is designed to investigate the feasibility of use of microorganisms, particularly bacteria, as a source of protein for man in long-term space missions. Initial work is being carried out on vegetative cells of Bacillus megaterium which is being used merely to serve as a model system. The short-term objectives of this program are to determine on a small scale the proximate composition of these cells, and the various methods of processing that would be suitable for the isolation of various cell components as edible material. The specific areas of investigation include:

1. Investigation of yields of utilizable protein available from Bacillus megaterium under optimum conditions of culture.

2. Development of methods for the extraction and preparation of this protein. These procedures will be designed to eliminate non-digestible and/or non-metabolizable and/or toxic materials in such a manner that a high quality edible product is produced.

3. Characterization of the major non-protein nitrogen components of Bacillus megaterium to enable the development of techniques for the selective removal of non-utilizable compounds.

4. Assessment in vitro of the amino acid composition and availability from any isolated protein preparation.

Work to date has centered mainly on refinement of techniques for growing cells to an optimum concentration in 20-liter batches, recovery of the cells, and determination of the proximate composition of the whole cell. Thus far studies have included:

1. Growth rates for Bacillus megaterium in a glucose-salt medium.

2. Cell recovery by continuous centrifugation.

3. Comparison of crude protein yield as determined by Biuret and Kjeldahl procedures.

Work has also been initiated to compare various methods of cell destruction in terms of their ultimate effect on protein yield. These methods include: total cell lysis by lysozme or penicillin, production of protoplasts with lysozyme, and cell fragmentation by sonication or mechanical shearing (French press).

COMMUNICATION SCIENCES RESEARCH

Investigator: H. J. Zimmerman
Project No.:   DSR 9829

The program for the coming year is a continuation of on-going basic
research in the various aspects of communication sciences. The
research seeks to increase our understanding of the fundamental
processes involved in the generation, processing, transmission and
utilization of signals in both natural and man-made systems.

The major research groups participating in the program include the
following:

> Linguistics
> Speech Communication
> Communications Biophysics
> Neurophysiology
> Cognitive Information Processing
> Processing and Transmission of Information
> Process Analysis and Synthesis
> Statistical Communication Theory
> Artificial Intelligence
> Computer Research

The character of the research is such that several of the groups
combine the efforts of individuals representing different disciplines,
and there are interactions between groups as a result of both over-
lapping interests and of dependence on related mathematics or on
similar experimental techniques.

The linguists are concerned with the structure of language, which
is fundamental to the formulation and expression of thoughts and
ideas. The studies in speech communication seek an understanding
of the process involved in producing speech sounds or of decoding
speech to recover the thoughts and ideas.

Sensory systems are studied both from the psychophysical and from
the neuroelectric viewpoint, with most of the effort currently being
devoted to the auditory system. Recent acquisition of a PDP-4
digital computer for use by the communications biophysics group
will greatly facilitate the conduct of experiments involving neuro-
electric data.

The study of cognitive information processes has continued with research on sensory aids, visual perception and picture processing. Computer simulation of experimental situations plays an important role in this research. Plans for the coming year include the development of a mobility aid simulator.

Statistical communication theory is largely concerned with the formulation and solution of nonlinear systems problems. Information processing and transmission is concerned with coding theory and modulation theory together with their applications to a variety of communication channels. In addition, switching theory and automata theory are actively under investigation.

Summaries of the research objectives of each of the groups appear in Research Laboratory of Electronics Quarterly Progress Report No. 76 (January 15, 1965). These summaries and lists of publications are submitted separately to the NASA Office of Space Sciences.

APPENDIX

PRINCIPAL INVESTIGATORS

ATHANS, Michael
    Assistant Professor, Electrical Engineering
    Postdoctoral Fellow in Engineering

BACKOFEN, Walter A.
    Professor, Metallurgy

BADDOUR, Raymond F.
    Professor, Chemical Engineering

BEVER, Michael B.
    Professor, Metallurgy

BLAIR, John
    Associate Professor, Electrical Engineering

BRIDGE, Herbert S.
    Lecturer and Research Physicist, Physics

BROCKETT, Roger W.
    Assistant Professor, Electrical Engineering
    Postdoctoral Fellow in Engineering

BROWNELL, Gordon L.
    Associate Professor, Nuclear Engineering

BUCHANAN, John M.
    Professor, Biology

COVERT, Eugene E.
    Associate Professor, Aeronautics and Astronautics

DAS, John B.
    Postdoctoral Associate, Nutrition and Food Science

de BRUYN, Philip L.
    Professor, Metallurgy

DIEBERT, Max C.
    Assistant Professor, Chemical Engineering

EVANS, Lawrence B.
    Assistant Professor, Chemical Engineering

FINSTON, Morton
    Professor, Aeronautics and Astronautics

GILLILAND, Edwin R.
    Professor, Chemical Engineering

GRIFFITH, Peter
        Associate Professor, Mechanical Engineering

GRUBER, William H.
        Assistant Professor, Industrial Management

HALFMAN, Robert L.
        Professor, Aeronautics and Astronautics

HANSEN, Kent F.
        Assistant Professor, Mechanical Engineering

HARPER, Alfred E.
        Professor, Nutrition and Food Science

HARRINGTON, John V.
        Professor, Electrical Engineering
        Professor, Aeronautics and Astronautics

HELD, Richard
        Professor, Psychology

HOFFMAN, Myron A.
        Associate Professor, Aeronautics and Astronautics

HOTTEL, Hoyt C.
        Professor, Chemical Engineering

HOWARD, Louis N.
        Professor, Mathematics

KERREBROCK, Jack L.
        Associate Professor, Aeronautics and Astronautics

KRAUSHAAR, William L.
        Professor, Physics

LERNER, Daniel
        Professor, Economics and Social Science

LIDSKY, Lawrence M.
        Assistant Professor, Nuclear Engineering

LIN, Chia-Chiao
        Professor, Mathematics

LORTZ, Dietrich G.
        Research Associate, Mathematics

MASON, Edward A.
        Professor, Nuclear Engineering

MATELES, Richard I.
    Assistant Professor, Nutrition and Food Science

McCUNE, James E.
    Associate Professor, Aeronautics and Astronautics

MEADOWCROFT, Thomas R.
    Assistant Professor, Metallurgy

MEISSNER, Harold P.
    Professor, Chemical Engineering

MICKLEY, Harold S.
    Professor, Chemical Engineering

MILLER, Sanford A.
    Assistant Professor, Nutrition and Food Science

MOLLO-CHRISTENSEN, Erik L.
    Professor, Meteorology

OATES, Gordon C.
    Associate Professor, Aeronautics and Astronautics

PINSON, William H., Jr.
    Associate Professor, Geology and Geophysics

REINTJES, J. Francis
    Professor, Electrical Engineering

RICH, Alexander
    Professor, Biology

ROHSENOW, Warren M.
    Professor, Mechanical Engineering

SAROFIM, Adel F.
    Assistant Professor, Chemical Engineering

SKOLNIKOFF, Eugene B.
    Research Associate, Economics and Social Science

SMULLIN, Louis D.
    Professor, Electrical Engineering

STICKNEY, Robert E.
    Assistant Professor, Mechanical Engineering

TANNENBAUM, Steven R.
    Assistant Professor, Nutrition and Food Science

TEUBER, Hans-Lukas
    Professor, Psychology

TOOMRE, Alar
     Assistant Professor, Mathematics

TOONG, Tau-Yi
     Professor, Mechanical Engineering

WITT, August F.
     Assistant Professor, Metallurgy

WOOD, Robert C.
     Professor, Economics and Social Science

ZAMES, George D.
     Assistant Professor, Electrical Engineering

ZIMMERMAN, Henry J.
     Professor, Electrical Engineering

STUDENT PARTICIPATION

Name and Status	Departmental Affiliation
Almasi, George S. Graduate Student	Electrical Engineering Research Assistant
Alpert, Ronald L. Graduate Student	Mechanical Engineering Research Assistant
Bartlett, Charles J. Graduate Student	Aeronautics and Astronautics Research Assistant
Bell, Adam C. Graduate Student	Mechanical Engineering Research Assistant
Bok, Enid C. Graduate Student	Economics and Social Science
Browand, Frederick K. Graduate Student	Aeronautics and Astronautics Research Assistant
Brockmeier, Norman F. Graduate Student	Chemical Engineering Teaching Assistant
Carlson, Alan W. Graduate Student	Electrical Engineering Research Assistant
Carlson, Roger W. Graduate Student	Nuclear Engineering Teaching Assistant
Chaudhari, Praveen Graduate Student	Metallurgy Research Assistant
Chinnaswamy, Srinivasan Graduate Student	Aeronautics and Astronautics Research Assistant
Conley, James W. Graduate Student	Electrical Engineering Research Assistant
Cooper, William W. Graduate Student	Chemical Engineering
Cuny, Jean-Pierre Graduate Student	Metallurgy
Dalzell, William H. Graduate Student	Chemical Engineering Research Assistant

Gendron, Aubrey S. Chemical Engineering
Graduate Student Research Assistant

Havlin, Robert H. Chemical Engineering
Graduate Student Research Assistant

Julian, William H. Mathematics
Graduate Student

Keating, Ronald F. Mechanical Engineering
Graduate Student Research Assistant

Kleinman, David L. Electrical Engineering
Graduate Student Research Assistant

Lee, Seon B. Mechanical Engineering
Graduate Student Research Assistant

Little, Winston W., Jr. Nuclear Engineering
Graduate Student

Mahoney, Francis J. Nuclear Engineering
Graduate Student Research Assistant

Manglis, Pericles C. Mechanical Engineering
Graduate Student Research Assistant

Mathews, Donald R. Nuclear Engineering
Graduate Student

McVey, John B. Mechanical Engineering
Graduate Student

Mobius, Mark Economics and Social Science
Graduate Student

Mukherjee, Debi P. Nutrition and Food Science
Graduate Student Graduate Assistant

Paradis, Stephen G. Chemical Engineering
Graduate Student

Rehm, Ronald G. Mathematics
Graduate Student

Ryu, Dewey D. Y. Nutrition and Food Science
Graduate Student Graduate Assistant

Salamitou, Jacques Metallurgy
Graduate Student Research Assistant

Schulze, Stephen R.   Chemical Engineering
Graduate Student   Research Assistant

Shaver, Paul J.   Electrical Engineering
Graduate Student   Instructor

Shu, Frank H.   Mathematics
Graduate Student

Silver, Richard S.   Nutrition and Food Science
Graduate Student   Research Assistant

Spiridon, Alexander   Electrical Engineering
Graduate Student   Research Assistant

Steinker, Gerald E.   Aeronautics and Astronautics
Graduate Student   Research Assistant

Sze, Kai-Kai   Chemical Engineering
Graduate Student   Research Assistant

Taylor, Kenneth B.   Biology
Graduate Student   Research Assistant

Todreas, Neil E.   Mechanical Engineering
Graduate Student   Research Assistant

Yamamoto, Shigehiko   Mechanical Engineering
Graduate Student   Research Assistant

Yarwood, John   Metallurgy
Graduate Student   Research Assistant

Yasuda, T.   Nutrition and Food Science
Graduate Student   Research Assistant

THESES

Author	Thesis Title	Degree	Department
Cuny, J.-P.	"Diffusion Measurements Using A Knudsen Cell"	S. M.	Metallurgy
Hastings, W. J.	"A Study of Near Free Molecule Flow Through An Orifice"	S. M.	Mechanical Engineering
Little, W. W., Jr.	"Reactivity Changes during Startup in Large Nuclear Rockets"	Sc. D.	Nuclear Engineering
Silver, R.	"Continuous Culture on Mixed Substrates"	S. M.	Nutrition and Food Science
Yasuda, T.	"Dynamic Response of Continuous Cultures"	S. M.	Nutrition and Food Science

COMMITTEES

Topics within the general program of the Center are selected with
the assistance of the following committees:

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N. S. Scrimshaw	Head, Department of Nutrition and Food Science
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